INSTITUTION OF GAS ENGINEERS

Abstracts of all Reports to be presented at the Autumn Research Meeting on Nov. 3 and 4 at the Institution of Mechanical Engineers

Report of the Gas Education Committee—1930-31

ADMINISTRATIVE.

The Council having decided—on the recommendation of the Gas Education Committee—that it would be appropriate and of greater use, if the annual Report of the Committee covered the normal Educational year, this Report deals with the period from May 13th, 1930 (the date of the last Report), to July 31st, 1931. Future Reports will relate to the twelve months ending on July 31st each year and—as is the case with this Report—will be presented at the Autumn Research Meetings of the Institution of Gas Engineers, instead of—as formerly—at the Annual General Meetings in June. The period covered by the Reports will not, therefore, correspond precisely with the Presidential year of the Institution.

The administration of the Education Scheme has been entirely reorganized during the year and is now operating effectively. A Calendar, giving the important events in the Gas Education Year, was issued to all concerned and materially expedited and facilitated the administration of the Education Scheme in general and the 1931 Examinations in particular.

The chief difficulty during the year has been the application of the regulations relating to the Examination of External Candidates in the subjects ancillary to Gas Engineering and Gas Supply. A special Examination for this purpose was held by the Institution in September, 1930, in order to accommodate existing candidates, after which the normal practice, whereby such examinations are conducted by the Educational Unions, was reverted to. In this connection, a meeting with the Secretaries of the Unions was held and arrangements were satisfactorily completed for the granting of facilities by the Unions, for the award of Ancillary Subject Certificates. Applications to sit for these Examinations should reach the Secretary of the Institution before January 31st in each year and not by February 28th as at present stated in the Education Scheme.

Since the Examinations under the Education Scheme provide a recognized means of entry to the various classes of membership of the Institution of Gas Engineers, it is important that the opportunities and facilities afforded by the regulations should be fully appreciated and utilized. The co-operation of all Gas Engineers and Managers is invited in drawing the attention of their employees to the provisions of the Scheme, copies of which may be obtained gratis from the Secretary of the Institution.

The District Education Committees are anxious to help all students and intending students and the addresses of the Honorary Secretaries of such Committees are given in the Appendix.

The Gas Education Committee has decided that 1932-33 shall be the final Session for the Examination of candidates who have been accepted in previous years with qualifications which are inadequate under the existing Regulations, and in future permission to sit for an Examination applies only to the next Examination available after such permission is given.

EXAMINATIONS, 1930.

The 1930 Examination Results in the Major Subjects [which have been published in the "JOURNAL"] show a slight decrease—due to the normal fluctuation—in the number of Examinees, as compared with the previous year.

The Charles Hunt Memorial Medal in the Diploma Examination in Gas Engineering for 1930—generously endowed by Mr. P. C. Holmes Hunt, on behalf of himself and his brothers and sisters, and in memory of their father—was awarded to Samuel McGown (Glasgow). The corresponding Medal for the Diploma Examination in Gas Supply was not awarded, there having been no entries for this Examination.

The statistical Results of the 1930 Minor Course Examinations—conducted by the City and Guilds of London Institute, under the auspices of the Institution—show a substantial increase in the number of candidates.

The Board of Examiners' Report on the 1930 Examinations indicates that the standard of work had not improved in all subjects.

EXAMINATIONS, 1931.

The 1931 Examination Results [which have also been published in the "JOURNAL"] show an increase in the number of Internal Candidates of approximately 14 per cent. over any previous year.

The Charles Hunt Memorial Medal in the Diploma Examination in Gas Engineering for 1931 was awarded to Alexander C. Rea, A.M.I.Mech.E., Assoc.M.Inst.Gas E. (Edinburgh). The corresponding Medal for the Diploma Examination in Gas Supply was not awarded, owing to the absence of candidates for this Examination.

As to the 1931 Minor Course Examinations, the number of candidates for the Final Examination in Gas Fitting was considerably greater than in 1930.

The Board of Examiners' Report on the 1931 Examinations indicates improved standards of work in both the Higher Grade and Diploma Examinations in Gas Engineering.

TEACHERS' COURSES.

Teachers' Courses in Gas Engineering and Gas Supply—organized by the Board of Education and conducted by Mr. C. H. Creasey, H.M.I.—were held in 1930 and 1931. The course at the Westminster Training College, London, S.W. 1, from July 21st to 25th, 1930, was attended by twenty-four Teachers, whilst at the course at Chancellor's Hall, Birmingham University, from July 6th to 10th, 1931, thirty-five of the thirty-six persons present were teaching. On the occasion of the latter Course, a valuable meeting of the Consultative Committee—comprising the Gas Education Committee, the Board of Examiners, and the Teachers—was held.

APPROVED MAJOR COURSES.

A List of the Centres conducting Approved Major Courses includes seven additional Courses approved by

the Board of Education and the Gas Education Committee during the year, viz.:—

3 Courses in Gas Engineering—Higher Grade.
1 Course in Gas Supply—Ordinary Grade.
3 Courses in Gas Supply—Higher Grade.

Approved Minor Courses.

The number of applications for the approval of Minor Courses, particularly in Gas Fitting, is indicative of the considerably increased interest which is being shown in the provisions made by the Scheme for the education and certification of craftsmen and others, many of whom do not wish to qualify for the professional side of the Industry. A List of the Centres includes twenty-two additional Courses approved by the Gas Education Committee during the year, viz.:

2 Courses in Gas-Works Practice.
1 Course in Gas Supply Practice.
19 Courses in Gas Fitting.

There has been an increase in the number of candidates for the Examination in Gas-Works Practice and 25 per cent. more Approved Centres presented candidates in Gas Fitting than in the previous year. This indicates the tendency which exists for students to study internally at an Approved Centre, instead of acquiring their knowledge by other means. The advantage which a student gains by studying a Course at an Approved Centre cannot be too highly stressed, and it is satisfactory to see that this is being recognized.

APPENDIX.

THE INSTITUTION OF GAS ENGINEERS.

LIST OF DISTRICT COMMITTEES.

District.	Chairman.	Secretary.
Eastern	A. Gregory	E. F. Keable, Engineer and Manager, Gas Works, Southtown, Great Yarmouth.
Irish	J. D. Smith	G. Airth, Gas Works, Dundalk.
Lancashire	W. J. Smith, B.Sc.	J. Alsop, Gas Street Gas Works, Bolton.
Midland	F. C. Briggs	H. R. Hems, Gas Department, Council House, Birmingham.
North of England	C. Dru Drury	H. Lees, J.P., Gas Office, Hexham.
Scottish	Dr. T. Gray	David Fulton, Gas Works, Helensburgh.
Southern (S.E.)	D. C. Cross	T. H. Prater, Gas Works, Margate.
Southern (S.W.)	R. Robertson	S. Hole, Gas Works, Bath.
Wales	H. D. Madden	O. Thomas, Gas Works, Pentre, Rhondda.
Yorkshire	J. Bridge	C. H. Chester, Gas Works, Wakefield.

2nd Report of the General Research Committee—1930-31

The work of the General Research Committee, which seeks to supervise and co-ordinate the research work of the Institution, is dealt with in this Report to the Council, under the headings of the Joint Research Committee, the Sub-Committees, and the Fellowship—with the addition, for the first time, of a Contributed Research Report. This latter Report—which will be followed at the earliest opportunity by a contribution on "Economy Flues for Gas Fires"—arises from the decision of the Council that private research laboratories should be permitted, as such, to submit Research Reports for presentation to the Institution. This decision has relation to the endeavour of the General Research Committee to co-operate more extensively with such laboratories and with undertakings and other organizations carrying out research work of general interest to the Gas Industry.

In this connection certain undertakings have co-operated in the testing of retort settings requiring hot-patching, whilst several of the Reports acknowledge the specific facilities which are being increasingly afforded to the Research Chemists of the Institution in furtherance of their investigations.

During the year new Research Sub-Committees have been formed by the Council to deal with Meters, Street Lighting, and Tar, and most technical aspects of the Industry are now covered by an appropriate Research Sub-Committee. It does not necessarily follow, however, that every Sub-Committee will present Annual Reports, there being much work which does not require or lend itself to publication.

The administration of the work of the General Research Committee has been re-organized and, *inter alia*, arrangements have been made whereby members of the Committee and of the appropriate Sub-Committees are kept informed of the activities of other technical organizations. In particular, copies of relevant technical papers are circulated for information, and members arrange to participate in the discussion on such papers and report thereon where necessary. The General Research Committee and the Street Lighting Committee visited the Watson House Laboratories of the Gas Light and Coke Company to inspect a special Exhibition of Gas Lighting Apparatus and Fittings.

The Report of the Livesey Professor to the Advisory Committee on the Livesey Professorship of Coal Gas and Fuel Industries at the University of Leeds for the Sessions 1928-29 and 1929-30 has been received and copies can be obtained from the Secretary of the Institution.

It might usefully be observed that, since the Presidential year ends at the conclusion of the Annual General Meeting in June and the Research Reports are presented at the Autumn Research Meeting in the following October, the work covered by such Reports does not correspond precisely with the year of office of the President, who is, *ex-officio*, Chairman of the General Research Committee. The membership of the Research Committees is given in this Report, or—in the case of Committees having separately published Reports—in the relevant Research Reports referred to herein.

Joint Research Committee of the Institution and Leeds University.

Two reports, both published separately, are made to the General Research Committee by the Joint Research Committee of the Institution and Leeds University as to its work during 1930-31, viz.:—

28th Report: Examination of the Products of Combustion from Typical Gas Appliances. Part VI.—Oxides of Nitrogen.

29th Report: 3rd Report on the Use of Creosote in the Manufacture of Carburetted Water Gas.

The *28th Report* of the Joint Research Committee extends the investigation of the products of combustion from gas appliances to oxides of nitrogen. Complete details are given of a method for their determination, based upon absorption in a solution of chromic acid in strong sulphuric acid and subsequent reduction to ammonia. Particulars of an alternative method using phenol sulphonic acid are also indicated.

The determinations of oxides of nitrogen have been confined to representative free-burning flames, viz., Argand, flat-flame, well and poorly aerated Bunsen, and Méker. The amounts of oxides of nitrogen produced were very small, ranging from 0·5 part per 10,000 by volume in the theoretical air-free products of combustion with the Méker burner to 1·0 part per 10,000 with the flat-flame burners. Little difference was found between the well-aerated and poorly-aerated Bunsen as regards

the production of oxides of nitrogen, nor did the addition of carburetted water gas to the extent of 25 per cent. of the mixture produce any noteworthy change.

The burners were mounted in the combustion chamber of a calorimeter and some 5 per cent. of the total oxides of nitrogen were removed in the condensate. This also contained about two-thirds of the sulphur of the gas and 0·08 per cent. of copper. An abstract of work by E. Terres upon the CO and NO production of flames is given, together with references to current research upon the determination of CO and the examination of gas appliances.

The 29*th Report* of the Joint Research Committee is an account of an investigation of the possibilities of using creosote in the manufacture of carburetted water gas. Creosote has been decomposed, either alone or admixed with gas oil, under conditions similar to those existing in the carburettor and superheater of a water gas plant. Further experiments, made at high temperatures, show the yields of gas which could be obtained from creosote by passing it through the fuel bed of the generator. The results of the work, some of which have been previously given in a summarized form in the 26th Report of the Joint Research Committee, indicate that the use of creosote for carburetted water gas manufacture is not promising. The present Report also includes results which show the influence of various factors, such as temperature, rate of oil supply, and the nature of the atmosphere, on the thermal decomposition of gas oil.

Calorimeters Sub-Committee.

Following upon the inquiry which the Calorimeters Sub-Committee made as to the experiences of users of recording gas calorimeters, instructions have been given for an investigation to be made by the Research Staff of one or more different types of instruments, when consideration will be given to the issue of a Report for the guidance of gas engineers.

Corrosion of Pipes Sub-Committee.

Arising from the 1st Report of the Corrosion of Pipes Sub-Committee relating to the Protection of Pipes against External Corrosion, a number of protected tubes and protective coatings and devices have been submitted to the Sub-Committee for examination. A visit to Germany was made to inspect the manufacture and use of a protected tubing, and recent American and German literature on soil corrosion is under consideration. The Wrought Iron Specifications of the Institution continue in general use as the basis upon which strip, tubes, and fittings are manufactured and ordered.

Gasholder Sub-Committee.

As a result of the issue by the Council of a letter to members as to the necessity for the periodical inspection and maintenance of gasholders and the keeping of a systematic record thereof, proposals have been made for the inspection and insurance of gasholders under contract. The technical considerations involved are under consideration by the Sub-Committee, whilst attention is being given to other suggestions relative to the maintenance of gasholders and the precautions to be observed in their erection and repair.

Liquor Effluents and Ammonia Sub-Committee.

The Liquor Effluents and Ammonia Sub-Committee was formed by the Council to co-ordinate and to continue the work formerly carried out separately by the Liquor Effluents Sub-Committee and the Ammonia Sub-Committee, which have previously made five and three Reports respectively. The newly constituted Sub-Committee now submits its First Report embodying "The Disposal of Liquor Effluents from Gas-Works" and "The Recovery of Ammonium Chloride from Circulating Liquor."

The former subject is in continuation of the 5th Report of the Liquor Effluents Sub-Committee, and deals with experiments with a cyclone tar separator at Foleshill Gas-Works at Coventry. Satisfactory results have been obtained under winter-load conditions. Laboratory experiments using a number of solvents for the recovery of phenols from ammonia liquor are recorded, together with the results obtained with an experimental counter-current washer, using crude benzole and a mixture of crude benzole and tricresyl phosphate as solvents. The recent results of the biological purification of spent liquor at Coventry are briefly reported and the further investigation of the destruction of effluent and ammonia liquor on the producer bars is noted.

The possibility of the recovery of ammonium chloride from circulating liquor is discussed, and its subsequent purification is considered.

Meters Sub-Committee.

The Sub-Committee will continue the consideration of the technical aspects of certain proposals for the periodical verification of gas meters and such other matters relating to meters as may arise from time to time.

Purifiers Sub-Committee.

This Sub-Committee continues to collect and collate data relative to accidents with purifiers and to provide advice when required as to the precautionary methods available for the avoidance of explosions, fires and personal injuries. The information of the Sub-Committee is that the number of such accidents continues to be relatively negligible.

Street Lighting Committee.

The First Report of the Street Lighting Committee (constituted by the Council on November 24th, 1930, and now the Joint Lighting Committee) is published separately.

It was prepared in order to draw the attention of those interested in Street Lighting to the necessity for increased Street Illumination and vigilance in the maintenance of the efficiency of lighting installations. The merits of gas lighting for streets on the grounds of quality of illumination, diffusion of light, absence of glare, reliability, and economy can be easily rendered ineffective where street lamp installations are inefficient or out of date. Accordingly, the Report is being issued to the Gas Engineer and/or Manager of all undertakings throughout the British Isles and to members of the Institution of Gas Engineers.

Based on the revised British Standard Specification for Street Lighting, No. 307, the Report indicates the advantages to be derived from compliance with the Specification generally and, in particular, from greater light-intensity, the closer spacing of columns, and increased heights of the light sources. Further, attention is drawn to the benefits which accrue from directional lighting and the use of clock controllers and governors, whilst formulæ are given for the calculation of foot-candle values from the known candle power of any light source.

Copies of the revised Specification, which should be read in conjunction with the Report, can be obtained from the Secretary of the Institution of Gas Engineers, price two shillings each, including postage.

Refractory Materials Joint Sub-Committee.

The 22nd Report of the Refractory Materials Joint Sub-Committee for 1930-31 is published separately. The work of the Joint Sub-Committee, which has been actively continued during the past year, is carried out in conjunction with the British Refractories Research Association under the Directorship of Dr. J. W. Mellor, F.R.S.

The greater portion of the Report of more especial interest to the Gas Industry consists of the investigation of "The Permeability of Refractory Materials to Gases" and "The Action of Carbon Monoxide on Refractory Materials." In each of these subjects, the completion of two sections of the work is recorded. In addition, work has been continued on the subjects of "Jointing Cements" and "Hot-Patching Cements," and progress Reports on these investigations are included.

Tar Sub-Committee.

On May 12th, 1931, the Council constituted a Tar Sub-Committee.

INSTITUTION GAS RESEARCH FELLOWSHIP.

The Research Fellow (Dr. A. H. Eastwood) and the Livesey Professor (Professor J. W. Cobb, C.B.E.) in the separately published Institution Gas Research Fellowship Report for 1930-31 deal with "The Influence of Inorganic Constituents in the Carbonization and Gasification of Coal. (I) The Interaction of Oxides and Volatilized Nitrogen Compounds. (II) Parallelism in the Production of Ammonia and Other Gases, particularly Hydrogen."

The work described is an extension of that recorded in the Report for 1929-30. Section (I) is an attempt to discover and explain the mechanism of the coal "liming" process. It was found that the increased ammonia yield was due to the interaction of the oxide and some volatile nitrogen compounds distilled from the coal. Section (II) deals with an investigation of a suspected parallelism in the production of gas and ammonia. It was found for a bituminous coal and an anthracite that a marked parallelism in the rates of production and the quantities of gas and ammonia evolved existed over the range 600° to 1000° C.

CONTRIBUTED RESEARCH REPORT.

In a separately published Report on the Combustion Standards of Gas Appliances—contributed by Mr. C. A. Masterman, M.A., F.I.C., and Mr. E. W. B. Dunning, B.Sc., A.I.C., on behalf of the Watson House Laboratories of the Gas Light and Coke Company and accepted by the General Research Committee—the results of combustion tests on over 400 gas appliances of various types are brought together in generalized form and certain conclusions are drawn. The physiological effect of the various gases constituting the products of combustion is discussed both in relation to the complete and incomplete combustion of town's gas. In normal circumstances unhealthy conditions cannot arise from the normal products, but if carbon monoxide is produced as a result of abnormal conditions serious danger to health may follow. The theoretical considerations affecting combustion are considered, with especial reference to the production of carbon monoxide, the only predisposing conditions being lack of access of air or a persistent flame chilling or a combination of the two.

The main body of the Report is concerned with analyzing the experimentally determined behaviour of various types of appliances in the light of the theoretical considerations governing combustion. The appliances are classified into three types: those having free burning flames; those having a restricted supply of air to the flame; and those in which the flames actually make contact with solid surfaces. If carbon monoxide is produced in appreciable quantities it is found to be due to well-defined and avoidable causes, perfectly consistent with theoretical considerations. In the absence of these causes the production of carbon monoxide is so low as to be negligible.

The results are summarized, and are interpreted into practical form governing the appliance itself, its installation, and its operation, for the ensuring of satisfactory combustion conditions. Details of experimental methods for carbon monoxide estimation are given, together with the results of carbon monoxide analysis in London streets.

28th Report of the Joint Research Committee of the Institution and Leeds University

Examination of the Products of Combustion from Typical Gas Appliances. Part VI.—Oxides of Nitrogen

Research Chemist: JAMES W. WOOD, M.Sc., A.I.C.

GENERAL INTRODUCTION.

By Prof. J. W. COBB, C.B.E., B.Sc., F.I.C.

The attention of Mr. J. W. Wood, assisted by Mr. W. J. G. Davey, has been specially directed to the study of the production of oxides of nitrogen by the combustion of gas in typical appliances. This constituent may be of interest in some cases on account of its physiological effects or its corrosive action, exercised directly or catalytically. It is desirable to be fully informed on these points and although, as will be indicated in the text of the report, various references have been made to oxides of nitrogen and their possible effects, we have only been able to trace one paper dealing specifically with the subject. It has therefore been investigated systematically and the results are embodied in the 28th Report.

One reason for the investigation is that many results reported for carbon monoxide in the past must have been rendered more or less unreliable by the unrecognized interference of oxides of nitrogen in the determination. It has been necessary to investigate closely what methods can be applied in order that these two constituents, carbon monoxide and oxides of nitrogen, can be determined separately and accurately.

In our previous reports the sources of error in the estimation of carbon monoxide have been examined carefully, a means for its accurate determination ensured, and the results obtained by the application of the method to the products of combustion of typical gas appliances have been published. The same is now being done for oxides of nitrogen.

There are two methods to which attention has been directed, one devised and communicated to us by Mr. A. R. Pearson, of the South Metropolitan Gas Company, and the other worked out by Messrs. Francis and Parsons in the Government Chemist's Laboratory. The determinations have so far been confined to the products of combustion from free-burning flames. It is evident that the amounts of oxides of nitrogen formed are very small, being of the order of 1 to 2 parts per 10,000 by volume in "theoretical" products of combustion free from excess air, and correspondingly less in the diluted products calling for examination in practice.

The report also contains information concerning recent work on carbon monoxide, the examination of the flames of gas appliances by a pyrographic method, and German standard specifications for the examination of gas rings and burners for domestic gas cookers.

The Committee would like finally to express its sense of obligation to the Gas Light and Coke Company, and to the Leeds Corporation Gas Department for the valuable facilities they have continued to provide for its work, and to the research staff, particularly Mr. J. W. Wood and Dr. F. J. Dent for the zeal and ability which has characterized their work throughout the year.

SUMMARY. By Mr. WOOD.

This report is a continuation of the previous reports of the Joint Research Committee upon the products of combustion from typical gas appliances. Attention has been directed to the determination of oxides of nitrogen, which are produced in minute quantities during combustion, and which possess both toxic and corrosive properties. Their presence has been indicated upon several occasions in previous reports.

We have demonstrated that a solution of chromic acid in concentrated sulphuric acid will hold back hydrocarbons and oxides of nitrogen. It is without action upon carbon monoxide, and hence provides a convenient substitute for liquid-air condensation for the purpose of preventing their interference during carbon monoxide determinations by the iodine pentoxide method.

Under suitable conditions the oxides of nitrogen may be caught in a relatively small quantity of the chromic-sulphuric acid reagent, in which they may be subsequently determined by reduction to ammonia with an alkaline reducing agent, distillation, and determination of the ammonia with Nessler's reagent.

A quantitative method using these principles was devised by A. R. Pearson, of the South Metropolitan Gas Company, and was kindly communicated to us. We have found that in order to obtain satisfactory results it is necessary to observe certain precautions very strictly.

Detailed particulars of the tests which we made cover the preparation of reagents; sensitivity and accuracy of the Nessler test for ammonia; distillation and Nesslerization of dilute ammonium chloride solutions; reduction of dilute nitrate solutions both in the presence and absence of the chromic-sulphuric acid reagent; reduction with various forms of zinc, granulated, arsenic-free, and foil; the time required for reduction; absorption of oxides of nitrogen; behaviour of nitrous oxide; the detection of small quantities of nitrites in solution.

The phenol disulphonic acid method for the determination of oxides of nitrogen in a form suitable for their determination in the products of combustion from gas appliances was specially worked out by Francis and Parsons in the Government Chemist's Laboratory. This provides a useful alternative to reduction methods, and the essential particulars are given. It uses much smaller quantities of reagent than are required for the reduction method, and should therefore give less trouble with "blanks."

All the tests of the present report have been made by the reduction method, which has proved quite satisfactory but very slow. Limitation of time alone has prevented working comparisons with the phenol sulphonic acid method, and it must not be concluded that we regard the reduction method as superior to the phenol sulphonic acid method. Each may have its advantages in special cases.

We have confined our determinations of oxides of nitrogen to free-burning flames (*i.e.*, those in which no obstruction or contact with the surface of a solid occurs), and have used the same burners as for the carbon monoxide tests of the 19th Report.

They comprise:

1. An Argand burner taken from a flueless heater. (Syphon stove.)
2. Two luminous flat-flame geyser burners. (No. 3 size.)
3. A laboratory type of Bunsen burner worked with hard and with soft flames. ($\frac{1}{2}$ in. tube.)
4. A medium-sized Méker burner. (80 m.m. head.)

The burners were conveniently housed in the combustion chamber of a Junkers' calorimeter, and the products were sampled from its flue outlet, sufficiently throttled to yield 6·5-8·5 per cent. CO_2 in the exit gases. The tests were made at the normal working rate for each burner, and with gas of 470 B.Th.U. gross per c.ft.

The oxides of nitrogen are initially present as nitric oxide, NO, and they are therefore expressed as the equivalent amount of NO in stating the results, which are given in the following three forms, each of which has its peculiar advantages:

1. The ratio of NO to CO_2 by volume in the products of combustion.
2. The proportion of NO by volume in the dry air-free products of combustion.
3. The volume of NO produced per 10,000 volumes of gas burned.

From the table it will be seen that the amounts of nitric oxide produced were very small, reaching a concentration of about 1 part per 10,000 by volume only,

Burner.	Gas Rate. C.Ft. per Hour at 60° Fahr. 30 In. Wet.	1 NO/CO_2 Ratio.	2 NO in Parts per 10,000 by Volume in Air-Free Products.	3 NO in Parts per 10,000 of Gas Burned.
Argand	6·55	0·00075	0·95	3·5
Geyser (1)	6·64*	0·00100	1·28	4·6
,, (2)	6·35	0·00104	1·40	5·1
Bunsen, well aerated	6·14	0·00066	0·83	3·0
Bunsen, poorly aerated	6·28	0·00072	0·93	3·4
Méker	8·94	0·00055	0·71	2·6

The above values are to be increased by 5-10 per cent. to allow for NO removed in the condensate.

* Total rate per pair of burners.

in the undiluted products of combustion. No exception could therefore be taken to them on hygienic grounds.

The NO production was greatest with the geyser burners, where the flames were spread out into thin sheets, and least with the compact well-aerated Méker flame. There was little difference between the well-aerated and the soft Bunsen flames.

The tests with the geyser burners could be divided into two groups. In (1) the gas from steamed vertical retorts was used; in (2) carburetted water gas was added to the extent of 25 per cent. of the mixture. No characteristic change in the output of oxides of nitrogen was observed.

In the above experiments the temperature of the outgoing products of combustion was about 18° C. (65° Fahr.), and the greater part of the water produced by the combustion of the gas was therefore condensed out. This water contained oxides of nitrogen equivalent to 13·3 mg. of nitric acid per 100 c.c., or 5-10 per cent. of the total NO production.

The average sulphur content of the gas was 26 grains per 100 c.ft., of which some 60-70 per cent. was removed in the condensate.

As demonstrating the corrosive action of this condensate, it may be pointed out that it contained copper sulphate equivalent to nearly 0·1 per cent. of copper, representing the removal of 24 grains of copper per 100 c.ft. of gas burned.

According to Francis and Parsons the proportion of oxides of nitrogen normally present in the atmosphere is 1-2 parts per hundred million by volume.

While in recent years considerable attention has been given to the very small amounts of carbon monoxide in products of combustion, oxides of nitrogen have been neglected, and only one published paper, that by Terres (1914), has been traced. It deals with upright and inverted incandescent lighting burners, and with heating flames.

In the case of three inverted incandescent burners, at normal gas rate and with normal aeration, the CO/CO_2 ratio was about 0·004, a value remarkably close to that given in our 25th Report for corresponding conditions, despite the fact that the gas used by Terres was of a much richer quality (585 B.Th.U. gross). The CO/CO_2 ratio for the upright incandescent burner was 0·003. Hydrogen was also found in the products of combustion to the extent of 20 to 50 per cent. of the amount of CO present.

The work on oxides of nitrogen showed a NO/CO_2 ratio of about 0·001, and was much less influenced by maladjustment of the burner than the CO production. Unlike the CO/CO_2 ratio, there was in the above tests an almost negligible difference between the NO/CO_2 ratios for the free-burning and partially obstructed flames respectively.

During the year we have continued to follow developments in the examination of the products of combustion from gas appliances, and notes upon recent work in connection with carbon monoxide are made. These include references to a paper by Mr. E. W. B. Dunning, of the Watson House Staff of the Gas Light and Coke Company; to the "Normen" or "Standard Specifications for the Testing of Gas Appliances" (including their products of combustion), issued by the Ger-

man Association of Gas and Water Engineers; and to some very important work by Dipl.-Ing. Frei, of Hamburg, upon the products of combustion and conditions of installation of water-heaters.

INTRODUCTION.

For several years now the Joint Research Committee has directed its attention to the examination of the products of combustion from typical gas appliances, paying particular attention to constituents, which although occurring in very small quantities, have nevertheless important influences upon the safe and efficient utilization of gas. Hitherto carbon monoxide has been the main subject of inquiry, and work on the carbon monoxide production of different types of gas appliances was reported in the 15th, 17th, 19th, 21st, and 25th Reports of the Joint Research Committee.

During the combustion of gas, or indeed any fuel, small quantities of nitrogen are oxidized and escape into the air with the products of combustion as oxides of nitrogen. The oxides of nitrogen are washed out of the atmosphere by rain, and nitrates are easily detectable in rain-water residues with a sufficiently sensitive test, such as the red coloration produced by brucine.

The oxides of nitrogen are important because they have slight toxic properties and an irritant action on the mucous lining of the respiratory passages; in addition to any corrosive action which they may themselves possess, they accelerate the oxidation of sulphur dioxide to sulphur trioxide in the presence of water vapour, and hence increase the corrosion of gas fittings and appliances.

The amounts of oxides and nitrogen formed are very small. Even under favourable conditions and in plant specially designed to give the maximum yield, the proportion of oxides of nitrogen in the products of combustion does not exceed 1 per cent.* by volume.

In the case of domestic gas appliances the amount is of the order of 1-2 parts per 10,000 by volume in the theoretical dry air-free products of combustion, and proportionately less as the products are diluted with excess air. The experimental difficulties are therefore as great, if not greater, than those encountered in the earlier CO determinations.

Throughout our CO determinations we had to watch closely for irregularities due to the presence of oxides of nitrogen, and the reports mentioned contain numerous references to experiments upon the holding-back of oxides of nitrogen (*e.g.*, 15th Report, and especially 19th Report, of the Joint Research Committee).

Nitrogen is probably oxidized to nitric oxide (NO) in the flame and then combines with the oxygen of the excess air as the waste gases escape from the zone of active combustion. The oxidation is, however, relatively slow at the concentrations met with in practice.

Nitric oxide is not readily absorbed by alkalies, and this probably explains some of our difficulties in removing the oxides of nitrogen during CO determinations. Some alkalies were more successful than others (*e.g.*, "Sofnolite," see 19th Report), but the improved results obtained when an oxidizing agent was introduced into the train (*loc. cit.*), indicated the direction in which a solution might be expected.

Some years ago considerable attention was given to the production of oxides of nitrogen during combustion, and an important paper on this subject, with a comprehensive bibliography was published by E. Terres in 1914. Since that time a few papers have appeared dealing with the determination of small amounts of oxides of nitrogen (chiefly in connection with the manufacture of explosives, or their use in mining practice), but the figures given by Terres represent practically all the published data respecting the output of oxides of nitrogen by gas appliances, and there is clearly a necessity for amplifying this work and bringing it up to date.

Reference might be made here to an unpublished Report kindly placed in our hands by the Government Chemist, in which the production of oxides of nitrogen during combustion receives considerable attention. The methods of analysis used were afterwards published by Francis and Parsons in the "Analyst."

The method used by Terres consists in allowing sufficient time for the nitric oxide in the products of combustion to oxidize, and then absorbing the higher oxides in caustic potash. The nitrate and nitrite caught in the alkaline solution are reduced to ammonia which is distilled over into a known amount of standard acid, and the excess is titrated. In some tests liquid-air cooling was used for the more efficient retention of the oxides of nitrogen. The principal defects of the method lie in the very large volumes of products which must be dealt with, and the small differential titration upon which the result is based. For example, typical tests taken from Terres' paper show the use of 50 litres of products of combustion and a titration of only 1-2 c.c. of N/10 sulphuric acid. We therefore sought other methods for the determination of the oxides of nitrogen.

If the oxides of nitrogen could be got into solution, the methods used for the determination of nitrates and nitrites in potable waters should be applicable, and the phenol sulphonic acid process has been developed for this purpose by several workers. Notable among these are Allison, Parker, and Jones, of the American Bureau of Mines, and Francis and Parsons, of the Government Chemist's Laboratory. Francis and Parsons, working with synthetic mixtures of air and nitric oxide, were only able to obtain a yield of 40 per cent. by the method described by the above workers. They traced the discrepancy to inefficient absorption and oxidation, and the disturbing effect of an excess of alkaline salts upon the nitration of the phenol sulphonic acid.

The essentials of Francis and Parsons' method are given, and the data given in the original paper suggest that it is eminently suitable for the purpose.

Preliminary concentration of the oxides of nitrogen by liquid-air condensation is necessary in the case of very weak mixtures. Some trouble was experienced by Francis and Parsons in obtaining reagents sufficiently free from nitrogen compounds, and later work by Piccard, Peterson, and Bitting shows that this difficulty can be minimized without detriment to accuracy in other respects, by using a much smaller amount of hydrogen peroxide. Originally we intended to use this method, but our attention was diverted to an alternative which is in some respects more convenient.

In August, 1929, Vandaveer and Gregg published a description of a relatively compact and simple apparatus for the determination of small quantities of carbon monoxide.*

One important feature of this apparatus was the use of a solution of chromic acid in concentrated sulphuric acid for the removal of water vapour, hydrocarbons, and other compounds which might react with iodine pentoxide and so interfere with the accurate determination of CO. It thus dispenses with the use of liquid-air, which although entirely satisfactory is not available in many districts. A relatively large volume, 200-250 c.c., of the acid mixture is used in the apparatus.

The above paper led to the publication of a letter by A. R. Pearson, of the South Metropolitan Gas Company,† who pointed out that such an oxidizing mixture would also retain oxides of nitrogen, and that he was hopeful of developing a method whereby the oxides of nitrogen could not only be trapped, but could be afterwards quantitatively determined in the solution. This was to be done by reducing the absorbed oxides to ammonia by means of an alkaline reducing agent, distilling off the ammonia, and Nesslerizing the distillate.

Through the kindness of Dr. Charles Carpenter, Mr. Wood was given details of the method, and discussed with Mr. Pearson the promising results which had already been obtained. We were invited to subject the method to critical examination.

Our first work was carried out with solutions containing known small amounts of a nitrate, so that questions of efficiency of oxidation and absorption of the gaseous oxides of nitrogen did not arise.

The yield of nitrate as ammonia was for some time very disappointing, being less than 40 per cent. of the

* Final Report of Nitrogen Products Committee (Cmd. 482, 1920).

* "A Simplified Iodine Pentoxide Apparatus for the Determination of Carbon Monoxide in Flue Gas." F. E. Vandaveer and R. C. Gregg—"A.G.A. Monthly," Aug., 1929, pp. 469-74 and 508-9. Reprinted in "Gas Journal," 11th, 18th Sept., 1929, and Oct., 1929. Discussed also in 25th Report.

† "Gas Journal," 2nd Oct., 1929.

theoretical amount, and we had difficulty in obtaining reagents sufficiently free from nitrogen compounds to give "blanks" that could be used with any confidence. Later results showed practically quantitative yields after correction for the nitrogen content of the reagents, so that as regards determination of the absorbed oxides of nitrogen, the method is quite satisfactory. Experiments upon the best method of securing the absorption of the oxides of nitrogen from the products of combustion naturally followed the above tests.

Details of the method we are now using are given in the Report. The working out of this method has occupied much time, and an account of the experimental work leading up to it is given. In essentials it does not differ from that put forward by Mr. Pearson, but there are several departures from his procedure. We have found it necessary to adhere very closely to the conditions laid down in order to obtain consistent and quantitative results. Among the more important of these we should mention the form of the zinc, the time allowed for the reduction of the nitrate, and the use of rather larger quantities of water so that the whole of the ammonia can be distilled over. The method seems to be satisfactory but very slow, and its accuracy cannot be increased by collecting larger quantities of the oxides of nitrogen, since we have to dilute the final distillate to come on to a range suitable for the Nessler matching. An alternative method of securing absorption of the oxides of nitrogen in chromic-sulphuric acid was tried, and proved quite successful.

The Report gives the amounts of oxides of nitrogen which we have found in the products of combustion from the same series of free-burning flames as were examined for carbon monoxide in the 19th Report of the Joint Research Committee, namely, Argand, flat-flame, Bunsen, and Méker.

During the year we have continued to follow up literature dealing with the amount of carbon monoxide in products of combustion from gas appliances.

Communication from the Chemical Department of the South Metropolitan Gas Company.

Estimation of Traces of Nitric Oxide.

Preparation of Chromic-Sulphuric Absorbent.

In previous work this had been prepared by dissolving chromic anhydride (CrO_3) in strong sulphuric acid. Difficulty was, however, experienced owing to the presence of traces of nitrogen compounds in the reagents, and it was found preferable to use recrystallized sodium dichromate* instead of chromic anhydride. A few grams of the finely-powdered dichromate are shaken with the sulphuric acid until the solution is saturated. The clear deep-red liquid is poured off and allowed to stand for a few days in a well-stoppered bottle. Some deposition usually occurs, and the clear liquid finally contains 3 to 4 grams of CrO_3 per 100 c.c.

Experimental Procedure.

Place 4 grams of pure zinc, 2 grams of A.R. crystallized ferrous sulphate, about ¾ stick of A.R. potash, and 250 c.c. of distilled water in a 1-litre conical flask fitted with tap funnel and double splash-head adapter. Distil off 50 c.c. portions until the distillate no longer gives a colour with Nessler's reagent.

Wash out the chromic-sulphuric reagent containing the absorbed oxides of nitrogen into a small flask and neutralize it by adding the potash used for the determination of carbon dioxide in the same experiment. This potash will, of course, contain any NO_2 which the waste gases contained, although separate determination showed that practically none of the nitric oxide underwent oxidation. Distil the alkaline chromate solution (which has a volume of about 150 c.c.) as described previously for the alkaline reducing solution, until the distillate is free from ammonia, and wash the residual liquid into the alkaline reducing solution.

Continue the distillation of the mixed liquids until 50 c.c. of distillate no longer give a colour with Nessler's solution. The ammonia in this distillate is determined colorimetrically by means of Nessler's solution, using a standard solution containing ammonium chloride equivalent to 0·00001 gm. ammonia per c.c. A blank experiment is carried out on the reagents used.

A. R. Pearson.

14th November, 1929.

* A later private communication states that the more usual potassium dichromate is equally satisfactory.

Terres' Paper Concerning Carbon Monoxide and Oxides of Nitrogen in Products of Combustion.

As noted in the Introduction, a valuable paper upon products of combustion was published by Dr.-Ing. E. Terres,* of the Technical High School, Karlsruhe, in 1914.

A General Summary by Terres.

Before summarizing his results Terres quotes experiments showing that even under unfavourable circumstances as regards ventilation it is very unusual for the CO_2 content of living rooms in which gas burners are working to rise above 1 per cent. Evidence is given of the harmless character of CO_2. The danger limit for CO is placed at 5 parts per 10,000, and upon somewhat slender evidence the same limit is accepted for nitric oxide.

The summary given by Terres is as follows:—

"In the present investigation the small amounts of carbon monoxide and nitric oxide which occur in flames are quantitatively determined from the hygienic point of view.

"Products of combustion from the following appliances were examined: Inverted burners, upright Auer burner, petroleum lamp, and candle. Further, the determination of nitric oxide was extended to include the products of combustion from heating flames. Special attention has been given to the inverted burner, since no experiments have hitherto been made upon it.

"It was found—

1. That all flames contain a very small amount of CO, approximately of the same order—namely, 0·2 to 0·4 per cent. of the carbon dioxide content; insufficient primary aeration increases this amount to 1·7 to 2·0 per cent. of the carbon dioxide.

(This conclusion is inconsistent with our own tests upon gas appliances at different gas rates, and upon free-burning and partially obstructed flames. Over-aeration may also lead to higher CO production. See Table below.)

Carbon Monoxide and Nitric Oxide Production of Flame:—Terres, Viehoff, and Raupp (summarized Wood).

Burner and Condition of Operation.	Range of Values. CO/CO_2 Ratio.	Range of Values. NO/CO_2 Ratio.	Average or Typical Values.	
			CO/CO_2.	NO/CO_2.
1	2	3	4	5
Upright Auer—				
Normal aeration . .	0·0026–0·0039	0·00065–0·00071	0·003	0·00067
Badly adjusted . .	..	0·00072–0·00266	..	0·0013
Mannesmann Inverted—				
Normal aeration . .	0·0041–0·0096	..	..	..
Auer-Otepe Inverted—				
Normal aeration . .	0·0019–0·0081	..	0·004	..
Graetzin Inverted—				
Normal aeration . .	0·0037–0·0056	0·00081–0·00135	0·005	0·0010
Under ,, . .	0·017 –0·049	0·00085–0·00116	0·028	0·00095
Over ,, . .	0·008 –0·016	0·00078–0·00081	0·011	..
With special globes .	0·0042–0·0078	..	0·004	..
Junkers' calorimeter .	..	0·00076–0·00110	..	0·00095
"Cooled flames" . .	..	0·00066–0·00115	..	0·0009

2. That all flames in the same way contain a constant and very small quantity of nitric oxide (0·0006 to 0·0017 vol. NO per vol. CO_2).
3. That the possible sulphur dioxide content of the

* "Untersuchungen über den Kohlenoxyd- und Stickoxydgehalt von Leucht- und Heizflammen. Ein Beitrag zur Hygiene der Flammenbeleuchtung." Von. Dr.-Ing. E. Terres (Aus dem chemisch-technischen Institut der Technischen Hochschule zu Karlsruhe) Journal für Gasbeleuchtung (now "Das Gas- und Wasserfach") Nr: 26, 1914, 605-13 und Nr: 28, 1914, S.700-6.

"Investigations of the CO and NO Production of Lighting and Heating Flames. A contribution to the Hygiene of Gas Lighting."

products of combustion calculated from the usual sulphur content of coal gas would amount to 0·00025 to 0·0012 vol. of SO_2 per vol. CO_2.

"From these results it appears that per vol. of CO_2 in the products of combustion of lighting and heating flames there is—

0·002 –0·02 vol. of carbon monoxide
0·0006 –0·0017 ,, ,, nitric oxide
0·00025–0·0012 ,, ,, sulphur dioxide

"With reference to the summary of the harmful limits of these various gases, it was shown that the concentration of all the above-mentioned constituents when air contains 1 per cent. of carbon dioxide are far removed from the harmful limits established by numerous hygienists.

"Experiments in a room of 48 cub.m. capacity showed that owing to natural ventilation, without special ventilation, a carbon dioxide content of ½ to ¾ per cent. in gas lighted living rooms was only seldom reached."

Recent Work in Connection with Carbon Monoxide.

In January of this year Mr. James W. Wood, Research Chemist, was invited to be present at a meeting of the London and Southern Junior Gas Association to hear a paper by Mr. E. W. B. Dunning, of the Watson House staff of the Gas Light and Coke Company. The paper was published in the "Gas Journal" of the 4th February with the title "Incomplete Combustion: Its Importance, Recognition, and Prevention," and the discussion was reprinted in the following issue of the "Gas Journal."

It was disclosed that at Watson House a simplified form of Vandaveer and Gregg's apparatus was being regularly used for CO determinations in the products of combustion from gas appliances (see 25th Report, Appendix (1)). The apparatus is very compact, and a solution of chromic acid in concentrated sulphuric acid is used instead of liquid-air for retaining hydrocarbons and oxides of nitrogen. By the use of samples of several litres of products of combustion (instead of 500 c.c. only) one of our principal objections to the apparatus is eliminated, and as the results are sufficiently concordant and in excellent agreement with those obtained with more elaborate apparatus, it would appear that the apparatus in question is very suitable for the routine examination of the products of combustion from gas appliances.

The consideration of water-heating appliances forms a very important part of Mr. Dunning's paper. It will be remembered that in the 19th Report recommendations were made as to the maximum gas rate, minimum flue length (3 ft.), and the maximum desirable CO_2 content (8·3 per cent.) in the flue gases for a 2½-gallon geyser. During the discussion of the paper these recommendations were criticized. Mr. Dunning showed satisfactorily low CO production without flue pipe, and with considerably higher CO_2 content than 8·3 per cent. in the exit gases.

Not only the size and type of the gas burners, but the size and shape of combustion chamber and flue passages may play an important rôle in determining the behaviour of a geyser; we realize that the results given in our 19th Report refer to a particular geyser (which was, however, regarded as a representative model) and the question of standardizing or enforcing the above limits does not arise. Mr. Dunning's paper clearly shows the necessity for examining a considerable number of sizes and types of water-heater before any general recommendation can be made, and it is hoped that work along these lines will be continued.

Through the courtesy of Herr Lempelius, of the German Association of Gas and Water Engineers, we have received a copy of the latest edition of the German "Standard Specifications for the Examination of Gas Rings and Burners for Domestic Gas Cookers."*

The examination covers:

(i) A full description of the appliance, especially of the burners.

(ii) Tests for gas-tightness of all parts carrying "live" gas.

(iii) Determination of the character of the flame, and its distribution with a pan in position.

(iv) The gas consumption, and the behaviour of each burner when turned low, especially as regards back-firing. The effect of using different proportions of coal gas and water gas is also ascertained.

(v) Examination of the products of combustion.

(vi) Determination of the thermal efficiency by a water-boiling test under carefully standardized conditions.

(vii) A summary of the results of tests and the expression of an opinion upon the construction of the appliance and its general suitability for domestic use.

Our immediate interest was in the examination of the products of combustion. A pan of cold water fitted with a Bunte sampling rim or funnel is used for the collection of samples, which are examined for CO by the Tausz-Jungmann modification of the I_2O_5 method. Full details of the test are given.

The requirements to be fulfilled as regards CO-production are as follows:—

"The CO content of the waste gases, based on the theoretical dry products of combustion should not exceed 0·10 per cent. by volume, either at full consumption or when turned down, whether only one or all the burners are in operation. Gas rings which are not free from objection in this respect will not be approved." It is understood that specifications and tests for other types of gas appliances are under consideration.

Arising from the publication of Appendix (4) to the 25th Report, "A Pyrographic Method of Examining the Flames of Gas Appliances," a letter from Herr Dipl.-Ing. Frei appeared in the correspondence columns of the "Gas Journal" for 15th April, 1931, claiming responsibility for this method of examining flames. The method was described by Frei in some detail in Das Gas- und Wasserfach, 1925, p. 757, and 1928, p. 1068. We communicated directly with Herr Frei and also made suitable acknowledgment of his claims by a letter in the "Gas Journal" of 13th May, 1931.

Herr Frei, in collaboration with Prof. Dr. med. L. Schwarz, and Dr. Phil. W. Deckert is at present engaged upon some most interesting work concerning the properties of water heaters, and the size of room in which they are placed. In a very friendly reply to our letter, he has furnished us with reprints of his papers.* These contain most extensive particulars of the dimensions, thermal efficiency and character of the products of combustion for a number of typical continental water heaters, worked with and without bafflers. The effects of down-draughts are also studied.

The safe limits of CO-contamination are discussed, not only for air of normal composition, but for air containing considerable CO_2 and with a diminished oxygen content. It is clear that this valuable experimental work will play an important part in framing any specifications which may be drafted for water-heaters by the German Association of Gas and Water Engineers, and it is receiving our careful consideration.

* "Normen fiir die Unterschung von Gaskochern und Kochteilen der Gasherde fiir den Haushalt" hereausgeben vom Deutschen Verein von Gas- und Wasserfachmännern e V. Reprinted from "Das Gas- und Wasserfach," 34 Heft, Aug., 1929 (12 pp.).

* "Über Gasbadeöfen und die erforderliche Badezimmergrösse," "Das Gas- und Wasserfach," 10 Heft 8 März, 11 Heft 15 März, 12 Heft 22 März, 13 Heft 29 März, 14 Heft 5 April, 1930. 2 Heft 10 Januar, 1931.

Report on the Combustion Standards of Gas Appliances

By C. A. MASTERMAN, M.A., F.I.C., and E. W. B. DUNNING, B.Sc., A.I.C.

INTRODUCTION.

The technique of testing gas appliances varies in this country from one laboratory to another, and moreover in any one laboratory progressive improvements in method and in appliance design make any representative comparison extremely difficult. Where some thousands of tests covering hundreds of appliances have been carried out, however, some broad generalization can be safely drawn, and the results have been felt of sufficient interest to justify the present report.

This report deals only with combustion tests, and is submitted as complementary to the several reports of the Joint Research Committee of the Institution and Leeds University. Those reports deal exhaustively with individual samples of appliances of the several types whereas the present report summarizes routine results, themselves of unequal merit, but covering a much greater number and variety of appliances, good, bad, or indifferent, as follows:—

Geysers	150
Wash boilers	25
Other water heaters	65
Cookers	50
Fires	40
Radiators	70
Miscellaneous	20

Throughout this report the results have been obtained on a gas having approximately the following composition and characteristics:—

	Per Cent.
CO_2	2·5
C_nH_m	3·5
CO	15·0
O_2	0·8
CH_4	22·0
H_2	48·0
N_2	8·2

C.V.—Gross, 500; Net, 454. S.G., 0·48

CO_2 produced	0.5 c.ft. per c.ft. of gas burnt
H_2O ,,	1·0 ,, ,, ,, ,, ,,
Air required	4·3 ,, ,, ,, ,, ,,

No convention has yet been adopted universally throughout the industry for the expression of carbon monoxide production. On the score of convenience there is much to recommend cubic feet of carbon monoxide per therm (gross) of gas burnt, and this has been used throughout the report. On the gas used the following represent the same carbon monoxide productions:—

C.ft. carbon monoxide per therm	0·1	0·5	1·0	5·0
CO/CO_2 (approximate)	0·001	0·005	0·010	0·048
C ft. carbon monoxide per 10,000 c.ft. gas burnt	5	25	50	250

Any report of this scope would have been impossible had it not been for the fullest co-operation the writers have received from their colleagues whose results have been embodied and suggestions adopted on so wide a scale that specific acknowledgment is impossible. In regard to the methods of carbon monoxide sampling and estimation which are in operation at Watson House under the supervision of Mr. F. C. Smith, F.C.S., the writers are especially indebted to Mr. Smith.

COMBUSTION PRODUCTS AND HYGIENE.

Complete combustion results in the formation of water vapour, carbon dioxide (with associated oxygen deficiency), and small quantities of sulphur dioxide in proportions directly dependent upon gas rate and composition. If combustion is incomplete there are added carbon monoxide (and hydrogen) in appreciable quantities and sometimes aldehydes, acetylene, and hydrogen sulphide. Traces of oxides of nitrogen are probably always produced.

Water Vapour.

The natural evaporation of moisture from the skin can maintain the body at comfortable temperature even in hot surroundings. High relative humidity in the air reduces this evaporation and discomfort follows—*e.g.*, tropical climates, overcrowded rooms. It is to prevent the creation of high temperatures and high humidity that flues should be fitted on certain gas appliances.

A geyser of 75,000 B.Th.U. per hour gross heat input will produce about $\frac{1}{10}$ lb. of water vapour per minute. If at 80 per cent. efficiency no condensation takes place this vapour in the absence of a flue will pass into the room together with 125 B.Th.U. per minute sensible heat (ignoring losses from bath, &c.). Most of this heat will be dissipated to and through the walls, but assuming sufficient remains to raise the air temperature from initial 60° Fahr. at the rate of $\frac{1}{2}$° Fahr. per minute in a room 1000 c.ft. capacity this water vapour will raise the relative humidity from 70 per cent. to 100 per cent. in about two minutes.

If the same heat input to the room is obtained from a flueless radiator or similar appliance the gas rate, and so the amount of water vapour produced, will be greatly reduced. If a stable condition is reached when the room temperature is 65° Fahr., outside temperature 40° Fahr., and ventilation of two air changes per hour, the relative humidity will remain unchanged inside and out at about 70 per cent. If the heating is carried out without passing the products into the room but with other conditions remaining unchanged the relative humidity will fall to below 30 per cent. (Psychrometric "effective" temperatures will be 59° Fahr. and 50° Fahr. respectively, the latter being below comfort zone.)

Extremes of humidity should be avoided if health and comfort are to be maintained. The symptoms of discomfort following the use of unventilated gas appliances of high consumption have often undoubtedly been due to the high consequent humidity. It has been stated that the wet bulb temperature preferably should not exceed 70° Fahr., and certainly should not exceed 75° Fahr. The former figure corresponds to 80 per cent. saturation at 80° Fahr. and 65 per cent. at 85° Fahr.

Carbon Dioxide and Oxygen Deficiency.

In times past it has been usual to judge degree of air vitiation by the concentration of carbon dioxide (*e.g.*, Factory Act. 0·12 per cent. CO_2 maximum). The origin of this method of estimation is undoubtedly the presumption that this CO_2 being of human origin will be an indicator of associated bacteriological matter. Carbon dioxide is in no sense a toxic gas. Lung air contains 5·6 per cent. CO_2, and by this is controlled the whole respiratory mechanism. A small increase speeds up the respiratory rate, while a decrease has the opposite effect. Use is made of this fact in the treatment of certain gas poisoning casualties (*e.g.*, CO) where increased lung ventilation is desirable and oxygen mixed with 5 per cent. or 10 per cent CO_2 is administered. Under normal conditions exposure to a concentration of 2 per cent. CO_2 (oxygen 17·5 per cent.) results in a deeper breathing although the effect is not usually noticeable subjectively. At 4 per cent. (oxygen 14 per cent.)—a concentration at which matches are extinguished and candles will not burn—panting and discomfort are produced, but no ill result beyond headache will follow even prolonged exposure. Before this concentration is reached gas combustion will be affected and carbon monoxide may be produced.

Sulphur Compounds.

Sulphur dioxide and traces of trioxide are the natural products of the sulphur compounds, chiefly carbon bisulphide, in the original gas. The quantities produced are directly related to the gas rate and the initial sulphur content. The pungent odour of sulphur dioxide, appreciable, at 0·0003 per cent. or less, produces definite discomfort before the maximum safe concentration for prolonged exposure (over 0·001 per cent.) is reached.

The smell of hydrogen sulphide is appreciable at about 0·0003 per cent., but only slight symptoms follow ex-

posure for several hours to hydrogen sulphide concentration of 0·005 per cent.

Oxides of Nitrogen.

Of the several oxides possibly produced, nitrogen peroxide is the most toxic having a serious effect on health at less than 0·01 per cent. At this concentration its presence is noticeable.

Aldehydes and Acetylene.

Both may sometimes be detected in small quantities in the products of incomplete combustion, and it is possibly the former which is partly responsible for what is called "the smell of incomplete combustion." Neither is present in sufficient quantity to have any physiological significance.

Carbon Monoxide.

Incomplete combustion may be dangerous to health owing to the relatively large amounts of carbon monoxide which may be produced. The toxicity of this gas is very much less than that of such common gases as ammonia, chlorine, sulphuretted hydrogen, or sulphur dioxide, but since it does not possess the characteristic or intolerable smell of these gases its presence in dangerous concentrations may not be suspected.

Exposure to 0·2 per cent. carbon monoxide for one hour is definitely dangerous. It appears to be agreed that 0·02 per cent. carbon monoxide is a perfectly safe concentration for prolonged exposure, but that concentrations above this limit are undesirable.

Mixed Gases.

There is some evidence that the toxic effect of mixed gases may be somewhat greater than the sum effect of the several gases separately considered. Even so it requires abnormally bad conditions of combustion and ventilation before the products from gas appliances can be anticipated as likely to have ill effect upon health.

In view of the stress presently to be laid upon carbon monoxide production it may be of interest to state that during the ignition or stoking of a coal fire the concentration of CO in the flue gases may exceed 0·1 per cent. A motor exhaust may contain over 5 per cent. In consequence of motor traffic the air of city streets is by no means free from the gas, as the following figures show:

	Per Cent. Carbon Monoxide.
New York (average of 141 samples)	0·008
Paris	0·001–0·005
Leeds (Meadow Lane)	0·0005
London (traffic blocks), mean of 31 samples	0·005
London (Vauxhall)	0·001–0·006
Strand area—	
Maximum of 32 samples	0·007
Mean of 32 samples	0·002
Berlin (101 samples)—	
Six samples exceeding	0·015
Maximum	0·023

Although the normal production of carbon dioxide, water vapour, and sulphur dioxide represents a maximum which cannot be exceeded, this is not the case with carbon monoxide. In certain circumstances and for well-defined reasons the normal low carbon monoxide figure may increase to dangerous proportions. The remainder of this report is therefore primarily concerned with information regarding such predisposing conditions, the comparative rarity of which fails to compensate for their potentially serious consequences.

THE THEORY OF COMBUSTION.

Under normal conditions the minimum temperature to which mixtures of town's gas and air require to be raised before self-supporting combustion begins is about 700° C., but this temperature will be profoundly modified by dilution, composition, pressure, and temperature of environment. Thus, in an environment at normal room temperature, the heat losses at extreme dilution are sufficient to prevent self-supporting combustion taking place.

Complete Combustion.

For the combustion of gas to be complete it is necessary for all the combustible gases to have been in contact with sufficient oxygen for a long enough time at the temperature attained. In practice combustion takes place progressively since not only is access to oxygen not instantaneous, but at the maximum temperature in the flame (say, up to 2200° C.) dissociation may be appreciable.

In an absolute sense combustion is always incomplete, and were it not for the persistence of high temperature from the flame, this would usually be appreciable since the last traces of combustible gases are certainly not inflammable at room temperature. This assisted reaction provides an explanation of the fact that satisfactory combustion is possible when the air is reduced almost to theoretical requirements in appliances such as geysers. In such cases inter-flame contact, lack of flame individuality, and even flame lifting is sometimes consistent with complete combustion.

Incomplete Combustion.

Self-supporting gaseous combustion can result in incomplete oxidation for two reasons only:

(1) Inadequate oxygen supplies in or immediately adjacent to the combustion zone.

(2) Chilling out of the reaction before it is complete.

One or both of these causes may operate, but subsequent zones of high temperature with or without additional air often enable combustion later to proceed to completion. In extreme cases the products may be capable of self-supporting combustion at room temperature, and two separate flame zones may be established—*e.g.*, furnace and recuperator.

Oxygen Deficiency.

Where combustion is incomplete owing to slight oxygen deficiency, the final stage in the reaction will be the sharing out of the balance of the oxygen between the carbon monoxide and hydrogen in the presence of carbon dioxide, water vapour, and nitrogen. While the reaction rate of the hydrogen is nearly three times that of the carbon monoxide under the same conditions, the final theoretical equilibrium conditions for town's gas would not necessarily favour preferential oxidation of the hydrogen at the expense of the carbon monoxide.

Flame Chilling.

Flame chilling may inhibit combustion at any of its stages. The deposition of carbon from a luminous flame is familiar, but this is compatible with subsequent complete combustion of the remaining gases. Similarly the presence of formaldehyde may sometimes be recognized in the products of incomplete combustion. Flame chilling of the reacting gases in the final state of combustion may lead to the presence of carbon monoxide (and hydrogen) in the products unaccompanied by the characteristic "smell of incomplete combustion." For flame chilling to result in the survival of appreciable quantities of carbon monoxide in the products in the presence of sufficient quantities of oxygen for combustion it is necessary for the chilling of the reacting gases to persist until they have travelled away from the high temperature combustion zone.

The importance of sufficient primary aeration is emphasized as a means of avoiding incomplete combustion from flame contact whether due to true flame chilling or local smothering. The conditions associated with flame chilling may vary so much that it appears impossible to anticipate precisely on theoretical grounds the effect of initial gas composition upon carbon monoxide production, but a high initial combined carbon content and especially a high methane content will probably predispose towards a proportionally higher carbon monoxide production.

Vitiated Air.

Combustion may sometimes take place in air, the carbon dioxide concentration of which is high and the oxygen content of which is correspondingly reduced. This results in a flame of increasing size and decreasing stability. At 3 per cent. CO_2 (16 per cent. O_2) a match

will not burn, but if flame contact is absent gas combustion is complete. This result is in no way adversely affected if the air be contaminated with carbon monoxide of other origin (*e.g.*, street traffic), the products of combustion then being found to contain less carbon monoxide than the surrounding air.

THE COMBUSTION BEHAVIOUR OF APPLIANCES.

Domestic appliances may be divided into three classes according to their combustion conditions:

(*a*) Appliances having free burning flames—*e.g.*, drying cabinets, radiators, ovens.

(*b*) Appliances which by reason of restricted air inlet or flueways allow reduced excess air to pass through the combustion zone—*e.g.*, geysers and and certain other water heaters.

(*c*) Appliances the flames of which make contact with solid surface—*e.g.*, wash boilers, some other water heaters, boiling burners, grills, gas fires, and incandescent burners.

The above classification which refers to normal use only is by no means rigid. Excessive gas rate, deterioration of parts, or bad design may change the combustion sometimes with undesirable effect from one nominal classification to another.

No distinction is drawn between aerated and non-aerated burners since the contrast between the two is one of degree rather than of kind. In fact, flame envelope dimensions broadly confirm direct observation that the nominally non-aerated flames obtained with geyser jets actually achieve a degree of aeration from the head of the burner, although this is insufficient to make them suitable for flame contact conditions. The gas rate on such burners can often safely be reduced to less than 5 per cent. of full rate, while an aerated burner must be carefully designed and adjusted if it is not to light back at 10 per cent. of full rate. Such a burner when lit back may produce carbon monoxide upwards of 1 c.ft. per therm under flame contact conditions.

(*a*) *Free Burning Flames.*

The rate of production of carbon monoxide from free burning flames is generally less than 0·03 c.ft. per therm. Slightly higher figures are obtained from a luminous flame at under 1-10th full capacity, or from an aerated burner deprived of its primary air. The high degree of dilution of the combustion products from such flames and the comparable carbon monoxide content of ordinary air in these conditions renders accurate routine tests inappropriate. The figures for normal and twice normal pressures confirm a carbon monoxide production in practice of something less than 0·1 c.ft. per therm, provided the classification of free burning flames is maintained. Luminous burners have a limited stability against pressure, and if this limit is exceeded roaring and flame distortion may result. Although this is itself quite consistent with complete combustion the effect may lead to flame contact with consequent increase in carbon monoxide from this cause.

Gross increase in gas rate, whatever the reason, may lead to reduced excess air and cause the flame to cease to be free burning. Further increase may lead to smothering and/or flame contact. At normal gas rate, circulation and evacuation of flue gases may be sluggish when first lighted from cold (*e.g.*, bottom flue ovens). This will result in reduced excess air or even smothering, though later on conditions may become perfectly satisfactory.

Contrary to first expectations, a forced excess air may lead to increased carbon monoxide production presumably by carrying the last traces of unburnt gas too quickly from the hot zone (excess air per c.ft. of gas increased from 17·5 to 33 c.ft.; CO per therm increased from 0·1 to 0·4 c.ft.).

(*b*) *Reduced Excess Air.*

Assuming flame contact does not result, increase in gas rate has little effect upon the carbon monoxide production, which is of the order of 0·1 c.ft. per therm only, until in a well-designed appliance there may be practically no oxygen left in the flue gases. Thereafter the carbon monoxide production mounts rapidly.

Inadequate air entry ports, or inadequate flueways will result in decreased excess air at equivalent rates and an earlier increase in carbon monoxide production.

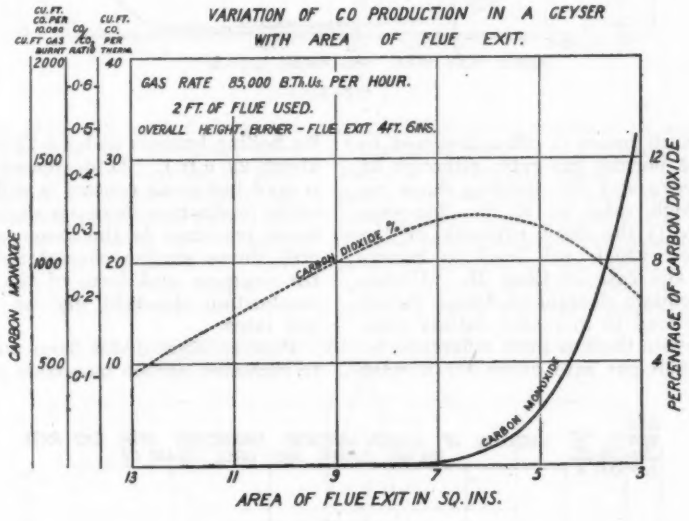
VARIATION OF CO PRODUCTION IN A GEYSER WITH AREA OF FLUE EXIT.
CU. FT. CO. PER 1000 CU. FT. GAS BURNT
CO/CO2 RATIO
CU. FT. CO. PER THERM
GAS RATE 85,000 B.Th.Us. PER HOUR.
2 FT. OF FLUE USED.
OVERALL HEIGHT. BURNER - FLUE EXIT 4FT. 6INS.
CARBON DIOXIDE %
CARBON MONOXIDE
CARBON MONOXIDE
PERCENTAGE OF CARBON DIOXIDE
AREA OF FLUE EXIT IN SQ. INS.

Fig. 1.

The change in carbon monoxide production from a geyser as the flue exit area is decreased is shown in Fig. 1. Expressed in terms of flue pipe diameter, the range of this graph is from about 4 in. to about 2 in. diameter, but in terms of the diameters of the boiler and shell the total dimensional change would correspond to less than $\frac{1}{8}$ in. on each. Owing to higher flue gas temperature and greater surface friction the flueways in the appliance require to be of greater section than the exit area—the precise section depending upon form and position.

Additional air can be drawn through the appliance, and often a greater overload margin obtained by a foot or so of primary flue extra to that required to offset the resistance of the baffler. In practice there is often insufficient head room for this addition, which at best may lead to ventilation difficulties by reducing in corresponding degree the length of secondary flue.

Increased carbon monoxide production will equally result from a restricted flue or from a defective baffler which allows downdraught to reach the appliance and so diminish the excess air to below minimum requirements.

The chilling of non-aerated flames by contact with waterways will usually lead to increased carbon monoxide production. This may be the result of excessive pressure which has led to flame instability at even lower rate than might be anticipated. High carbon monoxide produc-

tion may sometimes be reduced by lowering the pressure and substituting larger size burners to obtain the same gas rate.

(c) Flame Contact.

The larger margin between inner and outer cone and the precision of flame shape permit flame contact with aerated burners where with non-aerated burners both sooting and incomplete combustion would result. Flame contact is perfectly consistent with a carbon monoxide production of less than 0·2 c.ft. per therm.

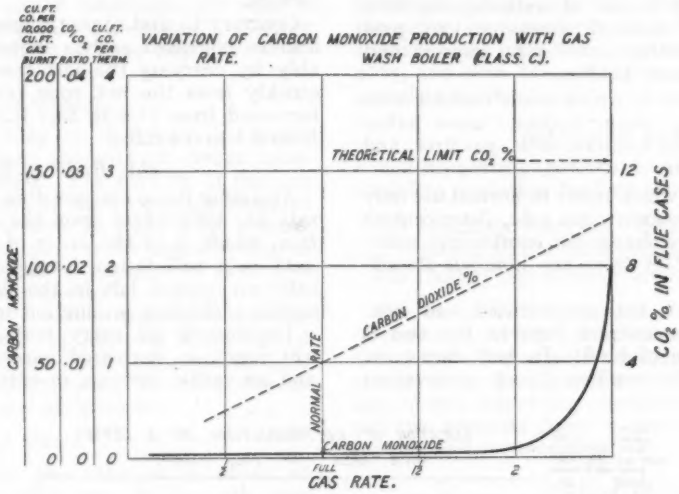

Fig. 2.

The burner under a wash boiler is often designed to produce flame contact at normal gas rate, although at reduced rates contact ceases and free burning flame results. At excessively high rates or if the flue-ways are inadequate (*cf.* Fig. 1) the limit capacity of the appliance may be passed which will lead to incomplete combustion as in the case of Class B. Under-aeration of flame or inadequate clearance between burner and bottom of pan may lead to increased carbon monoxide production. Otherwise there is little difference between the carbon monoxide-gas rate curve for a wash boiler and that for a geyser, except in the former that a greater overload margin is usually available and that the maximum carbon dioxide concentration is well below the theoretical limit since all the air does not pass through the combustion zone.

On waterheaters of the circulator type and on self-contained sets a clearer realization of the need for a low bypass rate, if scaling is to be avoided, is leading to the almost universal use of non-aerated burners in this country. Where flame contact and consequently aerated burners are relied upon the general arrangement becomes similar to that in the wash boiler except that a higher maximum carbon dioxide concentration is usually obtainable.

A hotplate boiling burner under a pot is superficially a similar arrangement to the wash boiler, but the carbon monoxide-gas rate curve is of different character owing to lesser flame space and absence of jacket. Little essential difference is found between the various types of burner in common use (Fig. 3 represents a mean curve for boiling burners under a 7½ in. pot, for gas rates up to about 22 c.ft.). At decreased pressures when aeration is poor but flame contact is still present the carbon monoxide production increases slightly and again falls at still lower pressures as the flame becomes free burning. A grill shows similar characteristics (Fig. 3) except that the nearness and form of the fret lead to a less good combustion standard and an emphasis of the peak at low rates.

Poor aeration under flame contact conditions may lead to increased carbon monoxide production owing to an inadequate amount of oxygen reaching the hot zone. The effect is especially marked if burner and solid are mounted too close to each other or if an excessively large pot is used. Excessive nearness between pot or fret and the burner may itself lead to incomplete combustion owing to local smothering and chilling of the flame. Rotation of a grill burner or displacement of the frets will have the same effect until the movement has proceeded sufficiently far for the flames to become free burning.

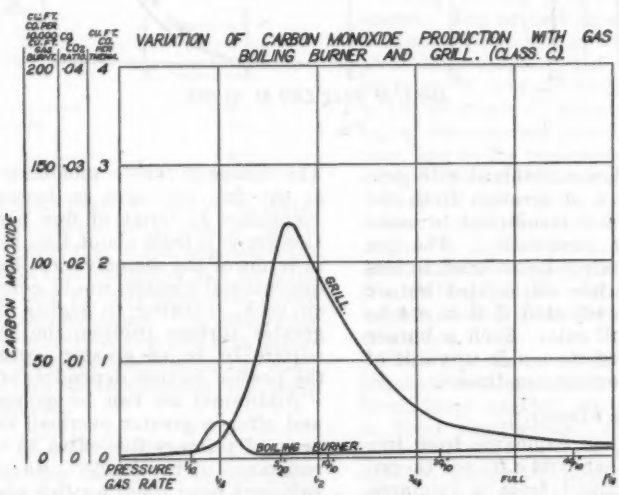

Fig. 3.

Before this happens a peak of 4 or 5 c.ft. carbon monoxide per therm may be reached.

In all these cases combustion tends to become complete at excessive gas rate owing to the flame extending beyond the solid boundary and there becoming free burning.

In the case of a typical gas fire (Curve (1), Fig. 4), properly adjusted for normal pressure the carbon monoxide production rises to a peak at excessive pressure just before the stage at which the flame burns outside the

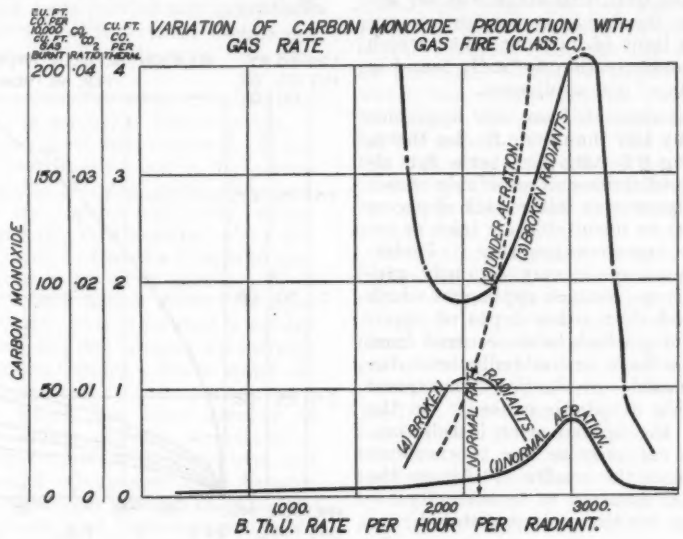

Fig. 4.

radiants. The products are normally vented from the top of the radiants with small excess air; the lower holes forming secondary air inlets. Further increase in pressure causes free burning flames to appear outside the radiants and the carbon monoxide production falls. Abnormally low aeration tends to increased carbon monoxide production (Curve (2), Fig. 4), as in the case of the grill or boiling burner, the precise result depending upon the design of fire and radiant. The

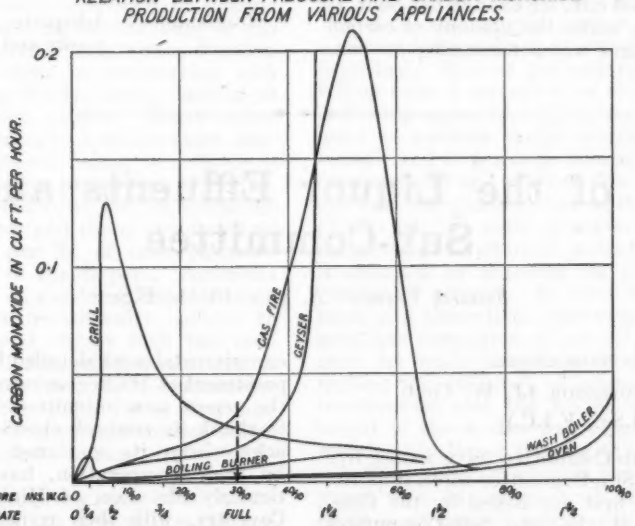
RELATION BETWEEN PRESSURE AND CARBON MONOXIDE PRODUCTION FROM VARIOUS APPLIANCES.
CARBON MONOXIDE IN CU. FT. PER HOUR.
0·2
0·1
GRILL
GAS FIRE
GEYSER
WASH BOILER
OVEN
BOILING BURNER
PRESSURE INS. W.G. 0
GAS RATE 0 1/4 1/2 3/4 FULL 1 1/4 1 1/2 1 3/4
10/10 20/10 30/10 40/10 60/10 80/10 100/10

Fig. 5.

effect of broken radiants on combustion depends upon circumstances (Curves (3) and (4), Fig. 4), representing extremely gross cases where the broken pieces were lying across the flames, producing local smothering consequent on breaking up of the inner cones. Inadequate ventilation of the radiants will lead to deterioration of combustion; a normal good radiant showing an increase in the carbon monoxide from less than 0·2 to over 1 c.ft. per therm when the holes at the back are closed up. Carbon monoxide production from two indifferently designed types of radiant showed reductions from 3 and from 9 to less than 1 c.ft. per therm when the tops of the radiants were broken off, and when additional holes were provided in the respective cases. The apparently different behaviour of lighting burners in giving increased carbon monoxide production at gas rates lower than the normal is probably due to the normal rate corresponding to an overload rate in the case of a gas fire, the flame of the former burning on or outside the mantle. The fact that peak lighting efficiency is obtained at this relatively late stage is possibly a catalytic or accelerated combustion effect produced by and in the mantle fabric. At reduced rates when the flame retracts into the mantle there is inadequate access of secondary air to the hot zone, the free area through the mantle being less than that through a gas fire radiant of the same consumption. Partial smothering results, possibly emphasized by the inverted position of the burner. (Radiants on portable heaters, having a close superficial resemblance to lighting mantles, show efficiency peak before carbon monoxide peak is reached as with gas fires; the normal rate is often above both these peaks.)

Conclusions.

The results of routine combustion tests on over 400 different appliances are found to be perfectly consistent with theoretical considerations derived from specific research on combustion phenomena. The conclusions are largely confirmatory of the several reports of the Joint Research Committee of the Institution of Gas Engineers

and Leeds University on Examination of the Products of Combustion.

With normal modern gas appliances properly adjusted but without flues the first physiologically appreciable effect in the absence of ventilation will be an increase in temperature and relative humidity. This will be succeeded by a perception of the presence of sulphur dioxide. At a later stage this would become intolerable and ultimately dangerous simultaneously with increase in respiratory rate due to the mounting carbon dioxide concentration. Not until this stage was far advanced would the carbon monoxide concentration approach the maximum safe limit of 0·02 per cent., which limit is in fact above the concentration normally found in the undiluted flue products of gas appliances.

The carbon monoxide production from any appliance at normal gas rate is usually less than 0·2 c.ft. per therm and a production exceeding 0·5 c.ft. per therm can always be attributed to some definite and avoidable cause. Increases well above this figure may follow lack of access of oxygen to the flame due to unsuitable air inlet or inadequate flueways, or to excessive gas rate. Under-aeration or inadequate flame space may seriously prejudice the combustion of flame contact appliances which are otherwise not less good than other types of appliances. Any cases of poisoning which have occurred from the products of combustion have undoubtedly been due to abnormal carbon monoxide production consequent upon one or several of these avoidable causes. In the absence of such defect in the appliance or installation, unsatisfactory combustion can only be due to excessive gas rate. Fig. 5 summarizes the results of this on the following normal appliances assumed to be correctly adjusted at 3 in. water gauge for the gas rates stated.

Oven	30 c.ft. per hour
Geyser	150 ,, ,,
Wash boiler	40 ,, ,,
Boiling burner	20 ,, ,,
Grill	25 ,, ,,
Gas fire	45 ,, ,,

The vertical scale of this graph is such that the maximum carbon monoxide ordinate of 0·2 c.ft. per hour can never lead to a carbon monoxide concentration in excess of the safe limit of 0·02 per cent. even in the absence of any flue, provided the natural ventilation of the room remains above 1000 c.ft. air change per hour.

Fig. 6 shows on differing scales the amount of carbon dioxide, sulphur dioxide, and water (assuming no condensation) produced by the same appliances under the same conditions.

Finally, interpreting the potential causes of unsatisfactory combustion into practical terms, hygienic freedom from carbon monoxide can be ensured by attention to the following points:—

Appliance: The provision of adequate air entry, combustion space and flueways, together with correct burner design, in relation to the desired gas rate. This rate must govern claims regarding heat output and efficiency.

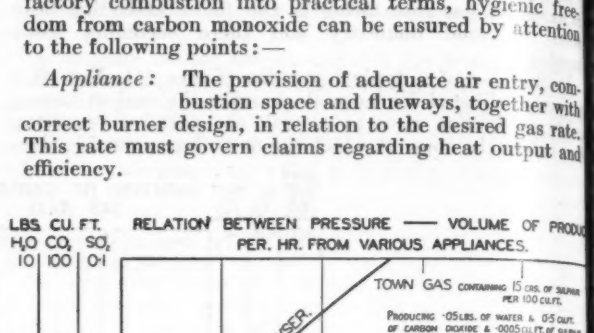
LBS. CU. FT.
H₂O CO₂ SO₂
RELATION BETWEEN PRESSURE —— VOLUME OF PRODUCTS PER. HR. FROM VARIOUS APPLIANCES.
TOWN GAS CONTAINING 15 GRS. OF SULPHUR PER 100 CU.FT.
PRODUCING ·05 LBS. OF WATER & ·05 CU.FT. OF CARBON DIOXIDE & ·0005 CU.FT. OF SULPHUR DIOXIDE PER CU.FT. OF GAS BURNT.
GEYSER
GAS FIRE.
WASH BOILER
OVEN.
GRILL.
BOILING BURNER
PRESSURE INS.
GAS RATE.
FULL

Fig. 6.

The workmanship employed and the materials used must be such as to maintain the critical dimensions of the original design during production and use.

Installation: Correct assembly of appliance, proper adjustment of gas rate and burner aeration (if any) and correct flue equipment (if any).

Operation: Control of local pressure variations to avoid excessive gas rate, or lighting back of aerated burners.

Maintenance: Adequate maintenance to remove deposits and repair mechanical damage.

1st Report of the Liquor Effluents and Ammonia Sub-Committee

Research Chemist: A. KEY, Ph.D., B.Sc.

GENERAL INTRODUCTION.

By the LIVESEY PROFESSOR (J. W. Cobb, C.B.E., B.Sc., F.I.C.).

The Liquor Effluents Sub-Committee have issued five Reports and the Ammonia Sub-Committee three Reports. The present Report is the first one issued by the Committee since the fusion of the two Sub-Committees originally constituted.

During the past twelve months Mr. W. A. Damon, the Chief Alkali Inspector, has accepted an invitation to join the Committee. Dr. Monkhouse resigned his position as Research Chemist on appointment as Alkali Inspector, and the Sub-Committee would like to thank him for the very valuable services rendered to both the Liquor Effluents and the Ammonia Sub-Committees from the time of their formation. His place has been taken by Dr. Key, who had previously been engaged on research work at Leeds with a grant from the Fuel Research Board. Dr. Key, with the assistance of Mr. Etheridge, has carried out the experimental work detailed below from the time of his appointment at the beginning of April, 1931, and has drafted the report now submitted. The Committee would like to thank its research chemists, and at the same time to acknowledge its continued indebtedness to others who, by their co-operation, have forwarded its work, particularly Mr. Lee, of Hinckley, and Mr. Langford, of Coventry, with their respective Committees and Staffs, and Dr. Happold, of the Department of Bacteriology of the University of Leeds, who has at times given special assistance and advice.

On the Ammonia side of its work the Committee has a special indebtedness to Sir E. John Russell, of the Rothamsted Experimental Station, and to Professor Norman M. Comber, of the Agricultural Chemistry Department of the University of Leeds. They were approached in order to obtain authoritative opinions based upon direct experiment on the value of compounds of ammonia other than sulphate as fertilizers. It was agreed that the best plan was to start with pot experi-

ents and to use these as a guide to subsequent plot experiments. The pot experiments have already been ut in hand by Professor Comber at Leeds on a repre-entative sample of ammonium bicarbonate supplied by Mr. W. Wilson, of Burton-on-Trent, and made by his rocess. The results are awaited with interest.

Dealing now with work carried out during the year, the Committee would emphasize that a considerable portion f it, undertaken mainly by the Chairman, Mr. C. F. Botley, with the assistance of the research chemists, con-ists of advice rendered and tests carried out in connec-ion with the special problems of individual Companies nd Authorities, and does not find its way into the Report.

The more systematic experimental work, of which the esults are detailed below, is mainly a continuation or levelopment of what has been previously reported. Static ashing experiments have been carried out in the labora-ory in order to determine the relative value of various olvents for phenol, and for higher tar acids, which atter have to be taken specially into account when any olvent extraction process is applied to the liquors of gas-works as distinguished from coke oven plants. It is pecially desirable to obtain information under this head ecause the process of recovering phenol by such a solvent s benzole has so far been applied almost exclusively n the large scale to coke oven liquors. These static ex-periments have been supplemented by others made on a mall experimental plant which has been erected at Coventry, and in which counter-current operation is possible. It has been shown that tricresyl phosphate and possibly tar oil have marked advantages over benzole for the extraction of the higher tar acids. In this con-nection, it is interesting to note that further experiments which have now been carried out at Coventry Gas-Works on the cyclone tar extractor have shown that both under summer and winter conditions this apparatus is very useful in effecting an early separation of those portions of the tar which are rich in higher tar acids. About 80 per cent. of the tar separated up to the outlet of the con-densers was brought down in the retort house and the cyclone tar extractor.

Systematic observation throughout the year has been made on the working of the bacteria beds at Coventry, which from the technical standpoint have continued to work satisfactorily.

An effective method previously described of dealing with effluent liquor by evaporation on the bars of gas producers has been given careful attention. Further experimental work has been done in conjunction with the staff of the Hinckley Gas-Works, and a section of the Report is devoted to that subject. There seems to be no doubt that this method of evaporation pro-vides an effective and economical means of evaporat-ing all the " devil " liquor and a proportion of the re-maining effluent, but it is expensive to use for evaporat-ing liquor in excess of the water and steam requirements of the producer—say, ½ lb. per lb. of coke gasified. Details are given in the text of the Report. Ammonia liquor can also be evaporated on producer bars although apparently with somewhat greater difficulty, subject to careful control as to quantity if unduly high fuel con-sumption and possibilities of increased corrosion are to be avoided. It is pointed out that such evaporation would be particularly applicable to the liquor first con-densed, which has the higher oxygen absorption value, due mainly to higher tar acids, and contains little free am-monia.

The Committee has, however, given most of its atten-tion to the utilization, and not the destruction, of am-monia. In this connection, the possibilities of producing ammonia in some form other than sulphate are being examined. The market for ammonium chloride is no doubt limited, but the preparation of this salt from the circulating liquor in which it is contained would seem to warrant consideration. More generally applicable would be a process for making ammonium bicarbonate.

The Committee has not yet had the opportunity of testing out the Burton-on-Trent process, which has been already described to the Institution and in which com-pression is used, but is giving special attention to the various possibilities which the production of ammonium bicarbonate presents.

SUMMARY.

The first section of this report records the continuation of a study of the effect of the use of a closed liquor-circulating system and a cyclone tar extractor acting on hot crude coal gas on the character of the ammoniacal and spent liquor produced. Tests at Coventry Gas-Works under summer load conditions were recorded in the 5th Report of the Liquor Effluents Sub-Committee, and further tests have been made in winter when a greater proportion of vertical retorts was in operation. It was found that when the flap valve of the cyclone was ad-justed to give a velocity in excess of 20 ft. per second to the entering gas, the tar was effectively separated. 84 per cent. of the tar condensed to the outlet of the water tube condensers was brought down in the retort house and cyclone tar extractor, the latter accounting for 3·0 gallons per ton. The effect of this was to reduce the higher tar acid content and oxygen absorption value of the spent liquor considerably, the average reduction in oxygen absorption value over a period of a year being 21 per cent.

Laboratory experiments on the removal of phenols and higher tar acids from aqueous solutions by means of solvents have been carried out at various temperatures. A number of solvents has been employed, and it has been found that crude benzole as obtained by scrubbing the gas at Coventry is as effective as 90's benzole and ap-preciably more effective than the 50's/90's benzole used in the experiments. The efficiency of phenol removal by these solvents is increased by raising the temperature, and most other solvents show a similar behaviour. Cresols are much more easily extracted by solvents than is carbolic acid, while catechol, taken as representing the higher tar acids, is much more difficult to remove. The efficiency of removal by benzole is considerably increased by the addition of aniline oil or tricresyl phosphate, when not only phenols, but a com-paratively large proportion of catechol can be extracted. Tricresyl phosphate alone is a remarkably good solvent for both phenols and catechol, 10 per cent. by volume being sufficient to extract 76 per cent. of the carbolic acid and 44 per cent. of the catechol from a solution of the two. In this case the efficiency falls somewhat with increasing temperature. Other solvents, paraffin, carbon tetrachloride and gas oil were unsatisfactory, but tar oils have given encouraging results. Further experiments are being made in this direction.

A semi-scale phenol washer erected at Coventry with a nominal throughput of 200 gallons of liquor per day is described. It is of the counter-current type, the liquor falling from a succession of sieves through solvent which is flowing upwards. Experiments have been carried out using as solvents crude benzole and a mixture of crude benzole and 10 per cent. tricresyl phosphate, and different temperatures and rates of flow have been employed. It has been ascertained that neither the rates of flow of the liquids nor the ratio of solvent to liquor is a very im-portant factor, although some increase in phenol removal is obtained by reducing the rate or increasing the pro-portion of solvent. It must be remembered, too, that there is a theoretical minimum proportion of solvent for complete extraction of phenol, this being about 43 per cent. for crude benzole at 60° C. The chief factors con-trolling the efficiency of operation are shown to be the temperature and the height of washer. Doubling the height of the washer has very nearly the same effect as washing the liquor twice with benzole. With crude ben-zole 69 per cent. of phenols were extracted at 60° C. com-pared with 44 per cent. at 12·5° C. This temperature effect is apparently mainly due to decreased surface ten-sion and increased kinetic energy of the molecules rather than to any increase of solubility as the temperature rises.

The quantity of higher tar acids removed in these tests was greater than was indicated by the static laboratory experiments, although complete removal of these bodies by benzole cannot be attained. The sulphide content of the liquor was decreased by as much as 45 per cent. by the washing process.

In a general discussion on the use of benzole as a solvent for phenols it is concluded that a loss of about half a gallon of benzole per gallon of recovered phenols would be entailed by the solu-

tion of benzole in the liquor unless some recovery process were adopted. For this purpose active carbon may be used or the liquor may be partially evaporated, and the benzole separated from the condensate. In order to obtain the best results both with regard to the amount of phenols recovered and the purification obtained, expressed on an oxygen absorption basis, it would be desirable to minimize the higher tar acid content of the crude liquor.

The use of tricresyl phosphate as a solvent is also discussed, and it is estimated that the high cost of this substance would be balanced by its decreased solubility in water, the ease with which phenols can be recovered from it by simple distillation, and its high solvent power for phenols and higher tar acids. It has not yet, however, been tried out on the experimental plant, so that these conclusions are tentative.

A brief account is given of the working of the bacteria beds at Coventry during the past year. The degree of purification has remained satisfactory, and does not appear to have been influenced by the fact that the fixed ammonia is now no longer being removed from the liquor.

Tests on the destruction of crude and spent liquor on the bars of the producers of Woodall-Duckham continuous vertical retorts at Hinckley Gas-Works are recorded. An amount of spent liquor equivalent to 16 gallons per ton of coal carbonized can be disposed of when the water normally supplied to the producers is replaced by liquor. No objectionable products result with the exception of a small quantity of sulphur dioxide in the flue gases, and there has been no interference with the normal working. To dispose of a greater quantity of spent liquor than that which displaces the normal supply of water to the producers would be costly in fuel, besides creating other difficulties. Calculation has shown that the cost in fuel alone of destroying the whole of the spent liquor by this process varies from £1 9s. 3d. to £3 15s. 4d. per ton of sulphate of ammonia depending on whether the liquor is from horizontal or vertical retorts, and on the presence or absence of waste heat boilers. The position is that a certain quantity of liquor can be disposed of in this way at a negligible cost, but that beyond this point the process is decidedly expensive.

The last section of the report points out the possibility of recovering ammonium chloride from circulating liquor. It is shown that by working-up the circulating liquor to a concentration of 12 to 20 per cent. of chloride, and then evaporating, a salt can be obtained which contains a comparatively small amount of impurity, and which can easily be purified. The advantages of recovering the fixed ammonia in this way, rather than as sulphate, are the saving in sulphuric acid and lime, and the production of a substance which at present commands a better price than sulphate.

1st Report of the Street Lighting Committee

The Street Lighting Committee of the Institution of Gas Engineers wish to emphasize the urgent necessity for special attention being paid to Gas Street Lighting installations throughout the country. It is recognized that improvements are being effected by various Gas Undertakings, but these, unfortunately, are not general.

The need for increased Street Illumination in these days of fast moving traffic and the growing public demand for safer thoroughfares are being recognized by Municipalities. The movement for better illuminated streets will accentuate the increasingly severe competition among lighting interests.

The Gas Industry cannot maintain its superiority in street lighting in the face of State-aided Electrical competition, if efforts are not continually made to ensure and increase its efficiency. Numerical predominance is not sufficient.

Although good Gas Lighting may be observed in one district, it does not necessarily follow that this fact will influence the lighting authority in another town where similar illumination results are absent. It may occur in such case that any change will be to Electricity, in consequence of the failure of the Gas Undertaking to keep its lighting up-to-date and/or by reason of the tendency of Lighting Authorities to follow the State in encouraging Electricity.

The merits of Gas Lighting for streets on the grounds of quality of illumination, diffusion of light, absence of glare, reliability, and economy can be easily rendered ineffective where street lamp installations are inefficient, or out of date.

British Standard Street Lighting Specification.

The British Standard Specification for Street Lighting, No. 307, which was issued in 1927 and revised in September, 1931, has been increasingly used where new or improved Street Lighting installations were under consideration. It is advisable that the Specification should be in the hands of every Gas Engineer or other official responsible for Street Lighting, and reference should be made to it for amplification of the requirements and terms used in this Report. Its use does not necessarily commit Gas Engineers to approval or otherwise of the minimum foot-candle basis of appraisement, which has been adopted as simple and convenient.

Copies of the revised Specification can be obtained from the Institution of Gas Engineers, 28, Grosvenor Gardens, London, S.W. 1, price 2s. each, including postage.

The purpose of the Specification is to provide bases upon which street illumination schemes can be provided and compared, and to specify technical conditions for the maintenance and appraisement of results. The general intention is to suggest the higher standards of illumination needed for modern day traffic and to effect better distribution of light and increased visibility. These objects can be achieved by greater light-intensity, closer spacing of columns, and increased heights of the light sources.

The adoption of a minimum illumination point for testing purposes (approximately midway in the space between columns), with the important stipulation of graduated illumination to avoid abrupt change along the street surface, was intended to encourage better distribution of light. Illumination near columns is usually more than sufficient, but this diminishes towards the area midway between the columns where, by comparison, the illumination is low and dark spots occur.

The classes of illumination with the appropriate mounting heights given in the revised Specification are as follows:—

Class.	Rated Mean Test Point Illumination on Carriage Way.	Height of the Luminous Centre of the Light Source above the Ground.	
		Minimum.	Lowest Recommended.
A	2·0 foot candles and upwards	30 ft.	30 ft.
B	1·0 foot candle	25 ,,	27½ ,,
C	0·5 ,,	21 ,,	25 ,,
D	0·2 ,,	18 ,,	21 ,,
E	0·1 ,,	15 ,,	18 ,,
F	0·05 ,,	13 ,,	15 ,,
G	0·02 ,,	13 ,,	13 ,,
H	0·01 ,,	13 ,, preferably	13 ,,

The above classes of illumination are based on horizontal plane foot-candle values under rated conditions—that is, values achieved when the lighting installations are in every respect new. Illumination under Service conditions must not be less than one-half of the rated value, but it should be observed that one of the advantages of Gas Lighting installations is that the illumination, under service conditions, will not fall so low as only 50 per cent. of the rated value, with ordinary maintenance.

The adoption of any particular class of illumination obviously must depend upon local conditions and the character of the street to be lighted.

The maximum spacing height ratios given in the revised Specification are:—

Class.	Maximum.	Recommended Maximum.
A	5	Not more than 3
B	6	,, ,, 4
C	8	,, ,, 5
D	9	,, ,, 6
E	10	,, ,, 7
F	12	,, ,, 8
G	12	,, ,, 10
H	12	,, ,, 10

The footway illumination, within 12 ft. of the kerb, is not to be less than 0·4 of the rated mean test point illumination, with the usual allowance of 50 per cent. for service conditions.

Application of the Specification.

The application of some of the provisions of the Specification depends to a great extent upon the views of the local Lighting Authorities, since financial expenditure is necessary to secure the improvement which results from an increase in the candle power of the light unit and the closer spacing of columns.

Where immediate alteration of this character is not possible, it is suggested that Gas Undertakings could in many cases achieve improvements which, though costing them little, would raise the illumination values and, at the same time, draw attention to the merits of Gas and help in its extended use for street illumination.

Gas Undertakings should fit up suitable lamps of modern type in one or more thoroughfares and direct the attention of the local Lighting Authorities to their possibilities. Laymen cannot be expected to keep themselves informed of gas lighting developments and local demonstrations are necessary.

Adoption of Modern Lamps and Burners.

It should be remembered that the comparison of existing gas lamps is usually with electricity used in up-to-date street installations; hence the advisability of displacing old-fashioned gas lanterns by modern ones and of providing the best type of burner equipment procurable.

When possible, the adoption of (say) No. 2 superheated burner sets in place of bijou burners, or an increase in the number of the latter would be a step in the right direction. In the case of square lanterns, the use of burners in line or staggered, instead of cluster formation, makes for better light distribution.

Heights of Light Sources.

The advantages to be derived by increasing the height of light sources are indicated by the two following examples:—

(*a*) Two triple No. 2 burner lamps, each yielding 180 c.p. and with 140 ft. spacing:—
Horizontal illumination at midway point—
Height 11 ft. = 0·011 ft.c.
Horizontal illumination at midway point—
Height 13 ft. = 0·013 ft.c.

(*b*) Two six-burner No. 2 cluster lamps, each yielding (say) 450 c.p. and with 100 ft. spacing:—
Horizontal illumination at midway point—
Height 12 ft. = 0·079 ft.c.
Horizontal illumination at midway point—
Height 15 ft. = 0·095 ft.c.

The maximum candle powers in the case of low-pressure inverted burners are usually obtained at angles of 40-50° below the horizontal, and it is obvious that the higher the light source the greater the range for illumination purposes.

If expense precludes the replacement of existing by taller lamp columns, the addition of an extension piece is not costly. Special castings to suit the design of the column can be procured at low cost. Failing these, the use of a 3 in. by 2 in. reducing socket on the column neck, the required piece of 2-in. pipe, and a final collar for a lengthened frog may serve the purpose.

Directional Lighting.

Directional devices, with which graduated illumination is achieved and no deprivation of existent illumination along a street surface is caused, have definite advantages, and such devices are now available for Gas Street Lighting.

It is not within the province of this Report to recommend any particular type of such device, whether consisting of enamelled reflectors, refractors, or mirrors, but it may be of service to give examples to illustrate the improved illumination which can be obtained.

An 8-cluster lamp fitted with (*a*) the ordinary reflector, and (*b*) a flat overhead and wing reflector gave the following results:—

Distance from Light Source.	Ordinary Reflector.	Directional Reflector.
10 ft.	0·67 ft.c.	0·72 ft.c.
20 ,,	0·35 ,,	0·40 ,,
30 ,,	0·18 ,,	0·22 ,,
40 ,,	0·09 ,,	0·19 ,,
50 ,,	0·05 ,,	0·12 ,,
60 ,,	0·03 ,,	0·06 ,,

Two ordinary lamps, each equipped with three No. 2 burners and tested with and without Holophane refractors afforded data as follows:—

Distance from Light Source.	Without Refractor.	With Refractor.
40 ft.	0·024 ft.c.	0·036 ft.c.
50 ,,	0·018 ,,	0·033 ,,
60 ,,	0·013 ,,	0·028 ,,
77 ,,	0·009 ,,	0·021 ,,

It will be noted that these devices raise the general illumination along the surface of the road, this increase being substantial in the mid-span area where additional light is needed.

The importance of the accurate fixing of these auxiliary aids relative to the mantles must be strongly emphasized. Cases have been noted where lack of attention in this respect has resulted in indifferent illumination.

Pressure Governors.

The use of governors is advisable in order to minimize the effect of variation of pressures where the variation is abnormal.

Automatic Lighting.

The adoption of clock controllers results in positive gain. Automatic lighting and extinguishing methods appeal to the general public and provide the advantage which is incorrectly attributed exclusively to electric light installations.

Closer approximation to schedule times for lighting and extinguishing in the case of all, instead of a limited number of lamps is rendered possible, and the saving of gas thereby effected covers that used by pilot jets. Mantle renewals are less frequent since breakages caused in torch lighting are avoided.

Controllers are also made to give dual service; that is, they will shut off part of the burner set at (say) midnight, and the rest at any other time desired. Economy is thereby effected.

Advantages of Gas Street Lighting.

Absence of Glare.

The relative absence of glare in the case of gas lighted streets is an advantage which is well worth bearing in mind. Ocular observation of this fact is indirectly corroborated by Dr. W. S. Stiles, of the National Physical Laboratory, in his report on experimental Street Lighting tests in Sheffield in July, 1928 (see "The Illuminating Engineer," September, 1929—page 240). The report stated "the mean glare estimate for No. 44 is anomalously low," and the installation "differs from the others in two important respects: (1) It has a very low mounting height, 15 ft., not permitted by the Specification in an installation with 0·25 foot-candles min. hor. illumination, and (2) it is a gas installation. The former of these is not likely to explain the anomaly, as the low mounting height is already allowed for in the computed effect of glare. If the latter is the cause, then we are led to the suggestion that of two lamps having the same effect on eye-sensitivity, one may be judged to be the less glaring."

Fog Penetration.

The greater penetration of fog and mist by gas light is generally recognized, and may be demonstrated where adjacent gas and electric light installations exist.

Reliability.

The reliability of a gas lighted installation is well known, and this applies both to the gas supply and the lamp equipment. Where lamps are fitted with units made up of several mantles, the temporary failure of one mantle does not necessarily affect the others and light is still available.

Economy of Lamp Charges.

The question of charges for public lamps is, of course, a matter for local decision. It would, however, seem desirable that the gas consumed should be supplied on at least the lowest terms given to consumers, in view of the quantity involved and the fact that a considerable proportion is used after midnight when consumption is desired. There is in addition the advertisement afforded.

The advantage which accrues from a low charge for gas is increased by the moderate cost of maintenance. The renewal of mantles is not expensive and by avoiding broken or frayed mantles the relative constancy of candle power is ensured. The latter is more important than low mantle average, and it is not always recognized that provided a mantle is unbroken its lighting power is practically unimpaired. The necessity for adequate maintenance generally cannot be too strongly emphasized, since it is essential that all lamps be kept in a state of maximum efficiency.

Electric Lamps.

The British Standard Specification for Tungsten Filament Electric Lamps, No. 161 (price 2s.), should be procured. It gives data of initial rating, life, performance, &c., of electric gas-filled lamps, and is generally useful for reference purposes.

CALCULATION BY FORMULÆ.

The following formulæ may be of service for the calculation of foot-candle values from the known candle power of any light source.

The " foot candle " is a unit employed to represent the illumination produced from the standard " International candle " on a plane at a distance of 1 ft. and normal (*i.e.*, at right angles) to the light ray. Since the illumination intensity is inversely proportional to the square of the distance between the light source and the test plane, the candle power of the lamps must be divided by the squared distance in feet to obtain the normal foot-candle value of illumination.

Normal foot-candle values in the case of street lighting can be calculated from the formula:—

$$\frac{I}{h^2} \times \cos^3\theta = E_n$$

Where I = intensity or candle power.
Where h = height of light source in feet.
Where E_n = the normal illumination in foot candles.
Where θ = the angle between the ray and the vertical.

The illumination values given in the British Standard Street Lighting Specification are obtained from light falling obliquely on a horizontal test plane used on the surface of the road. In this case the formula is as follows:—

$$\frac{I}{h^2} \times \cos^3\theta = E_h$$

Conversely, if the horizontal plane illumination is known the intensity or candle power of the light emitted can be calculated by the formula:—

$$\frac{E_h \times h^2}{\cos^3\theta} = I \text{ (or candle power).}$$

(Note: E_h is derived from one lamp only).

The candle-power intensities at various angles can be ascertained from the usual polar diagrams of light sources. The angle θ concerned can be ascertained by dividing the distance (d) measured from the lamp column to the test point by the height (h) of the light source, and the result will be the tangent of the angle made by the light ray and the vertical (column), thus:—

$$\frac{d}{h} = \text{tangent } \theta.$$

Reference to a table of tangents will give the required angle.

The distance (d) to the point at which the light ray at any definite angle θ shown on the polar diagram will strike the street surface is obtained by multiplying the tangent of the angle θ by the height (h) of the light source, thus:—

$$\text{Tangent } \theta \times h = d \text{ (distance from the column).}$$

Example.

An example of the use of the above formulæ is appended:—

Assume a lamp yielding 150 c.p. in the direction required—mantle centre 15 ft. high—distance to test point 75 ft. The angle in this case is 78·7°.

Thus $\frac{75}{15} = 5$, which tangent value gives the angle of 78·7°.

The cosine of 78·7° is 0·1959, and the cubed cosine 0·0075.

Hence $\frac{150 \text{ c.p.}}{15^2} \times 0{\cdot}0075 = 0{\cdot}005$ ft c. on the horizontal plane for one lamp, or 0·01 ft.c. for two lamps spaced 150 ft. apart.

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Institution Gas Research Fellowship Report: 1930-31

The Influence of Inorganic Constituents in the Carbonization and Gasification of Coal

By A. H. EASTWOOD, Ph.D. (Institution Gas Research Fellow), and J. W. COBB, C.B.E., B.Sc., F.I.C. (Livesey Professor)

INTRODUCTION AND SUMMARY.

In the Gas Research Fellowship Report for 1929-30 we described and discussed the influence of such inorganic materials as lime and oxide of iron on the liberation of nitrogen as ammonia from coal during carbonization and gasification. It was then shown that lime added to a strongly caking or medium caking coal increased materially the ammonia yield when the coal was heated in stages up to 1000° C. (totalling 9 hours' heating) in an atmosphere of nitrogen. This confirmed results obtained previously at the University of Leeds on the Corbet Woodall experimental plant, where the conditions resembled those of horizontal retort practice, and similar results long known to be obtainable by the liming of coal before carbonization. There has, however, always been some doubt as to how far liming could be relied upon to give more ammonia with different coals, and no satisfactory explanation has been forthcoming as to why lime should have this effect. In order to throw light upon this subject from one direction, experiments have been made in which the lime, in-

stead of being mixed with the coal prior to heating, was used in the form of a separate plug maintained at the same temperature as the coal, so that the lime could not influence the coal by direct contact with it (facilitating the expulsion of nitrogen as ammonia) but could exercise, if it were capable of doing so, its effect on the volatile matter expelled from the coal. This effect may be, and probably is, the summation of two opposed effects, the first being a dissociation of some of the ammonia present in the stream of volatile matter, into nitrogen and hydrogen, and the other a formation of ammonia by the decomposition of volatile nitrogen compounds present in the gas stream. The indication of the results obtained was clear. The amount of ammonia obtained when the lime was used as a plug was within experimental limits the same as when the lime was mixed with the coal. The influence of lime in increasing the ammonia yield was therefore clearly traced to its effect in decomposing volatile nitrogen compounds expelled from the coal, and not to an effect in actually expelling nitrogen from the coal in the form of ammonia. Calcium carbonate behaved similarly to lime. Using a plug of oxide of iron, rather more ammonia was obtained than in the absence of the plug up to 600° C. and rather less at and above 800° C., giving the same total ammonia up to 1000° C. In this case the oxide of iron, used as a plug where it could simply act upon the volatile nitrogen compounds, did not lower the ammonia yield from 700° upwards in the same way as it had done when mixed with the coal in previous experiments.

A plug of coke of very low ash content or one of silica raised the ammonia yield very slightly if at all, while one of alumina increased the yield, but not to the same extent as lime. The point to be stressed, particularly in the case of lime, is that its effect is exercised upon the stream of volatile matter, forming ammonia from nitrogen compounds contained therein.

A noticeable feature in tracing the production of ammonia on heating the (Sharlston Wallsend, Haigh Moor Seam) bituminous coal in nitrogen had been the marked maximum in ammonia evolution which always occurred at 700° C. In order to trace a suspected parallelism in the evolution of gas and ammonia, samples were taken of gas and ammonia at different times during each hundred degrees stage of heating, so that, for example, it was known not only how much gas and ammonia had escaped during heating for an hour at 600° C., or 700° C., but at what rates the gas and ammonia had come off at different times during these one-hour periods. A close parallelism is obtained between the expulsion of ammonia and of carbonization gases (mainly hydrogen), which would suggest that the compounds decomposing in the coal with maximum rate of decomposition at 700° C. were yielding gas and ammonia at the same time; the two products coming from the same compounds, or compounds so similar that they decompose at the same time. Confirmation for this view was found on repeating the experiments using anthracite instead of bituminous coal. With anthracite the temperature of maximum evolution of ammonia was higher, being 800° C. The same higher temperature was obtained for maximum gas evolution, and the same parallelism in gas and ammonia evolution as had been observed for the bituminous coal. The results obtained by Wheeler and by others on the evolution of gas from coal at different temperatures are as nearly consistent with those here published as can be expected, having regard to the somewhat different experimental conditions. It was, however, necessary to make the experiments herein recorded, in order to establish the close parallelism between ammonia and gas production in the region 600°-900° C. which was essential before we could put forward the view that the decomposition producing gas (mainly hydrogen), at 700° to 800° C., and that producing ammonia were so closely associated.

It is not suggested that the compounds decomposing to yield ammonia or gas at 700° C. existed as such in the original coal. They have resulted to some extent from the heating process. Thus even in such a simple compound as glycocoll it has been shown in (unpublished) work of Monkhouse and Cobb that the expulsion of ammonia on heating follows a somewhat similar course to that described above for coal. The effect of heating is to expel a portion of the nitrogen as ammonia at lower temperatures, but to form also heat-resisting nitrogen compounds which decompose at higher temperatures.

29th Report of the Joint Research Committee of the Institution and Leeds University

3rd Report on the Use of Creosote in the Manufacture of Carburetted Water Gas

Research Chemist: F. J. DENT, Ph.D.

GENERAL INTRODUCTION.

By the LIVESEY PROFESSOR (John W. Cobb, C.B.E., B.Sc., F.I.C.).

The 29th Report of the Joint Research Committee is a much more detailed account than has yet been presented of experiments carried out during the last three years on the position of creosote as a material for carburetting water gas, a subject on which two reports of a summary nature (the 24th and 26th) have already been issued. Comparison has been made of two types of creosote, gas-oil and mixtures of creosote and gas oil, varying in separate experiments the atmosphere, rate of oil supply, and temperature employed. The laboratory apparatus used was designed so as to give some approximation to the conditions of practice in essential respects. The results are given in detail with a discussion of their significance for the C.W.G. process in general and for creosote in particular.

The inferiority of creosote to a petroleum distillate as a carburetting material was clearly brought out, and it was shown that when mixtures of creosote and gas oil were used, each constituent might be regarded as being cracked independently, there being no special virtue in the mixing. Part of the hydrogen in the gaseous atmosphere was taken up in the hydrogenation of the unsaturated products of cracking. With an unfilled silica tube, or one packed with tubes of fused silica, there was remarkably little carbon deposited, but when crushed firebrick was used as a filling, corresponding more closely with large scale practice, the carbon deposit was increased considerably in amount, the nature of the contact material evidently being important in this respect. Very little of this carbon was gasified at the normal temperature of working by steam when that was present in the gaseous atmosphere employed. It may be mentioned that the separation and collection of the tar vapours issuing from the laboratory cracking furnace were found to be greatly facilitated by the use of a small electrostatic tar precipitator.

Some experiments have also been made with creosote in a specially constructed furnace at temperatures much higher than the red heat obtaining in the carburettor of a C.W.G. plant. These are interesting for various reasons, including the possibility of cracking creosote in the hot fuel bed of the generator.

Work has also been carried out on the reactivity of cokes at high temperatures. It is desirable to know to what extent the differences in cokes disclosed by reactivity determinations carried out at such temperatures as 900°

or 1000° C. persist when the comparison is made at much higher temperatures. It is quite true that for many purposes, reactivity at medium or even low temperatures is all-important, but it has to be borne in mind that in some industrial operations reaction of a coke with carbon dioxide or steam may be occurring at temperatures of 1200°, 1400° C., or higher temperatures. These experiments offer considerable difficulties and have exercised to the full the patience and ingenuity of the Research Chemist and his assistants. The general result appears to be that the differences in reactivity observed at medium temperatures persist, although to a less degree, at higher temperatures, but further investigation is required before definite statements or a report on this subject can be issued.

The 27th Report of the Joint Research Committee dealt with the "Back-Run Process for the Manufacture of Carburetted Water Gas," giving an account and analysis of tests carried out at the Stratford works of the Gas Light and Coke Company. This is being continued on a plant at Nine Elms which can be run successively with and without back-run (certain structural alterations being made for the purpose), and so will allow a direct comparison, unattainable by any other means, to be made.

Much of the time of Dr. Dent and his assistants has been taken up with this piece of work through the past twelve months, and some tests have already been run, but not enough to allow of the issue of a further report on the back-run process at this stage.

The Committee would like finally to express its sense of obligation to the Gas Light and Coke Company, and to the Leeds Corporation Gas Department for the valuable facilities they have continued to provide for its work, and to the research staff, particularly Mr. J. W. Wood and Dr. F. J. Dent, for the zeal and ability which has characterized their work throughout the year.

Summary of the Investigation.

By Dr. Dent.

The experiments described in this report were carried out to determine whether creosote, obtained by high temperature carbonization, could satisfactorily replace gas oil in the manufacture of carburetted water gas. Previous investigators, working on a full scale plant, showed that, when creosote was sprayed into the carburettor, the thermal yield of gas obtained was considerably less than the yield given by gas oil, and in addition, trouble was caused by the deposition of naphthalene. The naphthalene difficulties were reduced by diluting the creosote with gas oil, the creosote forming up to 20 per cent. of a mixture of the two. When so used it proved difficult, in tests made on the large scale, to estimate the yield of gas contributed by the creosote, and it was thought that under the controlled conditions of the laboratory, more accurate data could be obtained. With this object in view, an apparatus was erected and the experiments detailed below were made.

The main results of the investigations were given in a summarized form in the 26th Report of the Joint Research Committee. The behaviour of two different types of creosotes has been studied, at first, under conditions of temperature and atmosphere similar to those in the carburettor and superheater of large scale practice. One of the creosotes used was obtained from a tar produced by carbonization in steamed vertical retorts, while the other was a heavy creosote from horizontal retorts. Of the two the lighter creosote gave the higher thermal yield of gas, but the yield was approximately only from one-third to one-half of that given by gas oil. The bulk of the creosote went to produce tar which amounted to between 70 and 80 per cent. by weight of the original oil. The results of experiments in which creosote was diluted with gas oil showed that such a procedure did not lead to an increase in the yield of gas given by the creosote. Consequently in the 26th Report the conclusion was reached that the use of creosote in the carburettor of a water gas set, either alone or in admixture with gas oil, did not offer a promising method for its disposal.

The results obtained in this first series of experiments indicated that a greater thermal yield of gas might be given by the creosote if it were cracked at temperatures above 900° C. Temperatures higher than 900° C. are not readily obtained in the carburettor and superheater, but such temperatures exist in the generator, and, if it proved advantageous, the oil could be passed with the steam through the fuel bed. Accordingly, in a specially designed furnace, the temperature range studied was extended up to 1300° C., using atmospheres of hydrogen and steam.

The yield of gas obtained by cracking creosote in an atmosphere of hydrogen at such high temperatures was not greater than the yield at 900° C., viz., 0·65 therm. Actually, when the temperature was above 1100° C., the yield was less.

The tars obtained from creosote, when it was cracked at temperatures below 900° C., were liquid, when the considerable quantities of naphthalene present had been filtered off. In the experiment at 1000° C., however, the tar was in the form of a very dense pitch, while above 1000° C. the material which was separated from the gas was of a sooty nature, no liquid tar being present. This sooty material was in a very bulky form, and its amount was equivalent to more than 70 per cent. by weight of the oil used. It was anticipated that such material would give rise to difficulties if produced in the generator of a water gas plant. Consequently, it was interesting to ascertain whether the material could be gasified in an atmosphere containing steam, since such an atmosphere would exist in the fuel bed. The results obtained when creosote was decomposed in the presence of steam showed that the sooty material was extremely unreactive, and, at temperatures as high as 1300° C., the amount produced was not appreciably reduced by the steam. It is believed that the soot is mainly the solid decomposition product of the aromatic compounds in the creosote.

It is also to be remembered that the injection of oil into the generator would absorb heat from the fuel bed and consequently would lead to an increase in the coke consumption, and, since the maximum thermal yield of gas obtained from creosote still represented less than half of the heat of combustion of the original oil, the results of these experiments indicate that cracking creosote, by passing it through the fuel bed, would only prove economical under exceptional circumstances.

Before a satisfactory yield of gas is obtained by the thermal decomposition of creosote, conditions must be found under which the aromatic bodies, which are the major constituents of the creosote, are split up into gaseous hydrocarbons. Theoretically, this is only possible at extremely high temperatures. Qualitative experiments have been made in which naphthalene, typical of these aromatic substances, was passed over a tungsten wire, heated electrically to temperatures between 2000° and 3000° C. Observations showed that under such conditions some acetylene was produced, but, in these preliminary experiments, considerable quantities of carbon were formed, and the percentage of the naphthalene which was converted into gaseous hydrocarbons was small.

During the course of the investigation of the thermal decomposition of creosote, results, obtained in experiments using gas oil, were taken as standards of comparison. The considerable quantity of data so collected, indicated some of the factors which influenced the decomposition of the gas oil used, and it was thought that a discussion of the results could be included usefully in the report.

It was found that gas oil gave a maximum thermal yield of gas when decomposed at temperatures between 750° and 800° C.; the optimum temperature depended on the nature of the atmosphere and the rate of oil supply used. Below 750° C. a lower thermal yield of gas and a greater percentage of tar were obtained as a result of the decomposition of the oil being less complete, while hydrogenation of unsaturated hydrocarbons and, to a lesser extent, the splitting up of gaseous hydrocarbons into carbon and hydrogen, appeared to be responsible for the reduction in the potential heat in the gas when the temperature was above 800° C.

The results of experiments in which the nature of the atmosphere was varied, and of those which were carried out using different rates of oil supply, demonstrated the

important rôle played by hydrogen, when it is present during the decomposition of hydrocarbon oils. Some of the reactions which take place during the thermal decomposition of hydrocarbons are attended by an evolution of hydrogen, others by its absorption. The former type includes those reactions in which tarry matter is produced by the linking or condensation of molecules, and includes also the breakdown of hydrocarbons into carbon and hydrogen. On the other hand, the saturation of the unsaturated hydrocarbons, present either in the original oil or produced during the course of its decomposition, is accompanied by an absorption of hydrogen. In the experiments carried out with both creosote and gas oil below 900° C., in which hydrogen was present in the atmosphere supplied, the net result of all the reactions taking place was to absorb hydrogen.

It was found that the presence of hydrogen during cracking favours, to an extent dependent upon its concentration, those reactions which take place with its absorption, and retards those which are accompanied by its liberation.

It should be noted that hydrogenation of unsaturated hydrocarbons is generally accompanied by a liberation of heat, and, as a result, the potential heat of the total products is less than the sum of those of the original hydrocarbons and the reacting hydrogen. Consequently, from the point of view of gas production, the influence of the hydrogen is beneficial only in so far as it opposes the formation of tarry matter or the breakdown of gaseous hydrocarbons into carbon and hydrogen. The thermal yield of gas is decreased when the hydrogenation extends to the gaseous decomposition products, also, the probable hydrogenation of aromatic hydrocarbons to naphthenes, both of which classes of compounds are retained in the tar, has a similar result, since hydrogen is thereby removed from the gas. The results of experiments show, however, that within the normal limits of temperature and rate of oil supply of large scale practice, the net influence of an increase in the volume of hydrogen supplied, relative to the amount of oil used, is to increase the thermal yield of gas produced. Nevertheless the deleterious influence of excessive hydrogenation can be detected in the results of experiments in which gas oil was cracked at different temperatures. As indicated previously, the decrease in the thermal yield of gas in the temperature range immediately above 800° C. appears to be due to the conversion of gaseous unsaturated hydrocarbons into methane. From the results which show that the hydrogenation of gaseous hydrocarbons becomes more marked as the oil rate is decreased, and as the temperature is increased, it follows that the optimum temperature for carburetting is lower when making gas of low calorific value, using a correspondingly low rate of oil supply.

In the experiments described in the report the high yield of tar and the small amounts of carbon deposited in the tube are noteworthy. In this respect the results obtained do not agree with those of large scale practice. It is believed that this anomaly is in part due to the influence of the nature of the surfaces in contact with the gases and vapours during their decomposition, and, in designing an apparatus for the testing of gas oil, this feature should receive consideration.

No attempt has been made to review the numerous researches of other investigators on the cracking of oils, since the experiments described here were made with a specific aim in view, and it is realized that they are in no way complete when regarded from other aspects.

22nd Report of the Refractory Materials Joint Sub-Committee

REPORT ON THE WORK CARRIED OUT BY THE BRITISH REFRACTORIES RESEARCH ASSOCIATION.

(1) THE PERMEABILITY OF REFRACTORY MATERIALS TO GASES. PART I.

Experiments with Fireclay and Silica Products at Ordinary Temperatures.

By F. H. Clews, M.Sc., A.I.C., and A. T. Green, F.Inst.P., A.I.C.

Bull. B.R.R.A., No. 25, pp. 24-47, 1931.

Introduction.

The texture of a refractory product has a most important bearing on those properties which determine its durability in industrial usage. Porosity, considered as a general property of ceramic bodies, is intimately associated with the nature of texture. In consequence, porosity bears some relation to such features of industrial durability as corrosion, abrasion, and erosion, besides the more general properties of mechanical strength, density, and thermal conductivity. The degree of porosity, which is measured by the percentage of voids in the total volume, gives no indication of the nature, size, or distribution of the pores. It is not surprising, therefore, that in search for greater definition, properties which are more dependent on the characteristics of the pores are now receiving increasing attention. Permeability to gases is such a property. Besides the more fundamental aspects, the measurement of permeability has an immediate industrial significance. For instance, whilst it is often asserted that the main leakage in gas retorts and similar installations occurs at the joints, it is necessary to measure the permeability of the material of construction in order to vindicate this assertion. Further, in so far as the deterioration of a refractory product is due to penetration by corrosive vapours or even fine solid particles, the property of permeability will be a governing factor.

The materials selected for the experiments include representative samples of the better known silica and fireclay products of this country, together with a sample of a well-known brand of diatomite insulating material. The original paper gives the analytical data concerning the products, together with a description of their textures.

Table 1 gives the results of the porosity and permeability determinations on the materials of experiment. For the permeability data, which are reported in the units already considered, two values are given. These are the maximum and minimum values obtained for the specific materials. This variation is dependent on the position and direction of the sample in the brick itself, as well as on variations from brick to brick. In fact, wider limits might be obtained if more samples of the same brand had been examined.

TABLE I.

Material.	Mark.	True Porosity.	Apparent Porosity.	Permeability.	
				Minimum.	Maximum.
Aluminous clay product . . .	A	21·2	17·9	0·0219	0·0718
Fireclay product .	B	19·4	18·4	0·0031	0·0285
Fireclay product .	C	22·5	20·1	0·0364	0·1534
Fireclay product .	D	22·2	21·2	0·0315	0·0483
Fireclay product .	E	24·3	23·7	0·0271	0·1016
Fireclay product .	F	25·7	25·7	0·126	0·191
Aluminous clay product . . .	G	26·5	26·1	0·376	0·528
Fireclay product .	H	30·0	30·3	0·0170	0·0205
Fireclay product .	I	32·7	31·4	0·0916	0·1342
Siliceous product .	J	29·9	29·5	0·0557	0·1276
Silica brick . .	K	28·8	28·4	0·175	0·357
Silica brick . .	L	30·3	29·9	0·0671	0·0862
Silica brick . .	M	31·4	30·7	0·272	0·488
Silica brick . .	N	35·7	35·5	0·986	1·337
Diatomite insulating brick . .	O	70·3	70·2	0·0076	0·0288

A study of this table reveals that there is no definite relationship between the percentage porosity and the permeability coefficients. For instance, in the fireclay product series, A, B, and H show very low permeability values, but the apparent porosity of both A and B is in

the vicinity of 18 per cent., whilst that for H is 30 per cent. The grog brick G, with a medium porosity, has the highest value for the permeability.

In the straight silica brick series, N, with the highest porosity, also shows the highest value for permeability. In fact, excepting L, this series does suggest some relationship between porosity and permeability. However, much more work requires to be done before even a qualified statement on this point could be permitted.

In general, the porosity of a straight silica product is greater than that of an average fireclay product, and the results reported in Table 1 suggest that the permeability of the silica brick is, on the average, greater than that of a firebrick. The values for the diatomite insulating product O are certainly illuminating. Here we have a material of 70 per cent. porosity giving with one exception the lowest permeability of the whole series.

It has already been pointed out that the factors governing the flow of gas through a refractory are the number and dimensions, direction and nature, and continuity of the pore systems. Such properties are dependent on: (1) The grain size and grading of the raw batch materials; (2) the manufacturing processes, chiefly including pugging, shaping, and pressing; and (3) the firing period. The grain size of the raw batch and its grading, affects the permeability, (*a*) by governing the packing of the particles, and thus influencing the dimensions of the pores (if Poiseuille's Law for the flow of gases is applicable, permeability will depend on the fourth power of the average radius of the pore channel); and (*b*) by the influence it has on the vitrifying properties of the material. The manufacturing processes often determine a directional arrangement of the particles, whilst during the vitrification period of firing the amount, size, and shape, and to some degree the arrangement of the pores, are influenced.

Some consideration of the above factors in relation to the materials of our experiments can now be attempted. One of the influences of grain size is well illustrated by the highly-grogged bricks F and G of comparatively high permeability, whilst the firebricks B and H of somewhat fine texture show a low value for this constant. The brick D is described as having a close texture, but not so close as B, and its permeability is somewhat higher. In the silica brick series it is interesting to compare and contrast the materials L and M. Both textures are comparatively fine, although the adhesion of the grains in L is greater than in M. The permeabilities, however, are widely different, M having values about six times those of L. The grain sizes of the raw batch mixes of these two materials are known to be different. In some earlier experiments with samples of these products it was found that, whereas in the case of L, 50 per cent. passes through a 120's mesh sieve, only 20 per cent. of the raw mix of M does so. The major fraction of M, over 70 per cent., lies between a 20's mesh and 120's mesh. Obviously then, the packing of the grains in L will be closer than in M, and the probable development of a matrix during vitrification will be greater. On these lines, then, some explanation of the differences in permeability can be pursued.

To account for the very low permeability of the diatomite material O, it seems necessary to assume that the pores, although numerous, are excessively minute, bearing in mind that the permeability probably varies as the inverse power of the average radius of the pores. Of course, in this case, the porosity is not produced, except in a minor degree, during the manufacturing process, being present to a high degree in the raw material. It is as well to remember also the extreme thinness of the siliceous wall of the diatom, which is of the order of 0·00001 cm.

The vitrification period of firing for fireclay products may be considered as extending from 900° C., to the finishing temperature, which varies with the nature of the clay product. The effect of vitrification in reducing the apparent porosity of a body is well known, so much so that the reduction in porosity of a standard body is taken as an indication of the heat work during this phase of the firing. Whether the permeability is reduced during the vitrification period in a manner similar to the apparent porosity is a matter for future investigation. Actually it appears that there are reasons for thinking that such may not be the case in the early stages; it is probable that the permeability will decrease with increasing heat work, and therefore that well-vitrified bricks will show reduced permeability. With some materials another feature of the vitrification period is the formation of a dense surface layer, which would naturally tend to reduce the overall permeability of the product. Probably the origin of this dense exterior layer may lie in the earlier stages of firing or in the drying of the goods, but it is vitrification which actually forms it. Tests concerning these effects have been made and will be described later. There is, of course, a marked difference in the phenomena associated with the vitrification periods of fireclay and of silica bricks. The former is marked by a tendency towards contraction, and the latter by an expansion. How far these differing phenomena influence permeability is at the moment a matter for speculation, but it seems to offer a partial explanation of the differences in the values for silica and fireclay goods.

(2) The Permeability of Refractory Materials to Gases. Part II.

Experiments with Fireclay and Silica Products at Temperatures up to 500° C.

By F. H. Clews, M.Sc., A.I.C., and A. T. Green, F.Inst.P., A.I.C.

Bull. B.R.R.A., No. 26, pp. 44-56, 1931.

Introduction.

The work on the permeability of refractory materials to gases was undertaken primarily with the object of obtaining additional information regarding the characteristics of the various pore systems existing in present-day products, with a view to applying such knowledge to the better selection of refractories. Inasmuch as all refractories are employed at high temperatures it becomes of the greatest importance to investigate the effect of temperature on all the relevant fundamental properties. Accordingly, the permeability of a selection of refractory products has been measured in the present work at temperatures up to 500° C. It is hoped to continue the investigation at higher temperatures in the light of the experience gained in this intermediate temperature range. The account here given is, therefore, of the nature of an interim report, but it points the way as to what is to be expected at the higher temperatures operating in industrial service.

Summary.

1. A method is described by which the permeability to nitrogen of five fireclay, five silica, and one siliceous, materials has been directly measured at temperatures up to 500° C.

2. As the temperature increases the permeability is found to decrease, in a manner almost independent of the nature of the material and the value of its permeability coefficient at ordinary temperatures. For a temperature increase from 10° to 500°, the permeability is reduced to almost half its value for fireclay products, and to slightly less than this value for silica materials.

3. The increase in the viscosity of the gas with rise in temperature is shown to account almost quantitatively for the decrease in permeability, but, in addition, small variations in the results for the different products suggest the dependence to a minor degree on a further factor related to the pore structure of the material.

4. The inversions between 100° and 250° C. in the low specific gravity forms of silica are suggested as the explanation of the divergence of the results between the fireclay and silica products.

(3) A Comparison of the Rates of Flow of Water and of Air Through Refractory Materials.

By F. H. Clews, M.Sc., A.I.C., E. O. Mills, B.Sc., and A. T. Green, F.Inst.P., A.I.C.

Bull. B.R.R.A., No. 25, pp. 48-54, 1931.

The results of the water penetration and water permeability tests are such that when the products are placed in order of increasing penetrability, they are also

arranged in order of increasing permeability to water. This order is very nearly the same as that of increasing permeability to air. The water penetration test, it thus appears, may be used as a quick, qualitative comparison of permeability for the types of materials used in these experiments.

(4) The Action of Carbon Monoxide on Refractory Materials. Part I.

Experiments on the Disintegration of Fireclay Products by Carbon Monoxide.

By W. Hugill, M.Met., F.R.M.S., H. Ellerton, and A. T. Green, F.Inst.P., A.I.C.

Bull. B.R.R.A., No. 25, pp. 14-23, 1931.

It has been known for many years that carbon monoxide is capable of causing the disintegration of some fireclay products at temperatures reputed to be between 400° to 600° C. An examination of materials which have been ruptured in this manner generally show that the "iron spots" in the bricks have become filled with and surrounded by a fine, sooty carbon, disintegration being the result of an increase in volume caused by this deposition.

The reaction involved in the deposition of carbon is written $2CO \rightleftharpoons CO_2 + C$. It is reported that this deposition takes place between temperatures of approximately 350° and 700° C., and that the decomposition of the monoxide is accelerated by the presence of certain substances. Some of the main conclusions put forward in previous investigations can be summarized as follows:

(1) Ferric oxide acts as a catalyst towards the monoxide between certain temperatures, when copious carbon deposition takes place.
(2) Hard burning of the firebrick renders the material less susceptible to the action of the monoxide, but more prone to spalling from thermal shock.
(3) To prevent disintegration effectively the brick must be free from uncombined iron oxide.
(4) The ease with which a brick disintegrates is influenced considerably by the method of manufacture.

Experimental.

Samples of eleven types of fireclay and more aluminous products have been tested under strictly comparable conditions for the effects of clean, dry carbon monoxide at a definite temperature. The test-pieces were cut in the form of cylinders $\frac{3}{4}$ in. in diameter and $1\frac{1}{4}$ in. long. The flow of monoxide through the apparatus was maintained at 1 litre per hour. The temperature of the specimen was held at approximately 420°. After several preliminary trials it was decided to fix the maximum time for each test at 20 hours. Each sample was examined after it had been subjected to the action of the monoxide for about 5 hours, and any visible change in the specimen recorded.

Observations.

Out of the eleven specimens tested five resisted disintegration. The others showed breakdown, some being very badly affected. One product was broken down into pieces, $\frac{1}{4}$ in. diameter after $4\frac{3}{4}$ hours. After $16\frac{3}{4}$ hours this sample was disintegrated into very small pieces. Observations point to the fact that the disintegrating effect of the monoxide is mainly localized at the "iron spots." These "spots," in cases of breakdown, become very sooty. Sometimes the matrix of the brick becomes darkened, but this is not a general observation.

As shown in Table 1 there appears to be some correlation between the type of "iron spot" and the tendency of the brick to disintegrate under the action of carbon monoxide.

Discussion.

A study of Table 1, firstly, reveals that there is no apparent relationship between the "iron" content of the brick, as determined by chemical analysis, and the tendency to disintegrate. Although D and G contain comparatively high percentages of iron and show disintegrating tendencies, C, which contains 3·75 per cent. Fe_2O_3, resists the action of the monoxide, at least for 20 hours. On the other hand, A, containing only 1·69 Fe_2O_3, shows breakdown in the test.

Excepting materials A and B, where the disintegrating action was located at one or two "iron spots," the materials which have ruptured in the test contain the higher amounts of ferruginous matter extracted by bromoform. Thus D, E, G, and H contain over 0·1 per cent., whereas all the products which resisted the action, namely, C, F, I, J, and K, contain less than 0·1 per cent. of this separable ferruginous matter. Possibly, then, the separable iron compound (or compounds) plays an important part in the breakdown of the products.

Table I.

Mark.	Per Cent. Fe_2O_3 by Analysis.	Per Cent. Ferruginous Matter Extracted by Bromoform.	Per Cent. Area of "Iron Spots."	Colour of "Iron Spots."	Disintegration After 20 Hours' Treatment with Carbon Monoxide.
A	1·69	0·02	1·7	Cavities with blue-black crystals	+
B	1·33	0·01	1·8	Brown with a few black cavities	Slight
C	3·75	0·03	5·4	Solid black spots	—
D	3·12	0·46	14·4	Blue-black crystals in cavities	+
E	2·40	0·13	5·7	A few blue-black cavities	Slight
F	2·88	0·08	11·5	Numerous brown cavities	—
G	5·00	0·91	17·6	Blue-black crystals in cavities	+
H	2·40	0·13	9·0	Black cavities	+
I	2·50	0·08	5·6	Brown cavities	—
J	2·34	0·02	2·4	Brown cavities	—
K	2·52	0·07	5·5	Brown cavities	—

The measurement of the relative area of the "iron spots" does not appear to have given data which at the moment is capable of much correlation. The information may, however, serve to give a reason for the very rapid breakdown into small pieces of the samples D and G. Microscopic examination reveals, however, certain facts which at this stage of the work appear to be very important. In samples of four of the six bricks which showed breakdown in the monoxide test, blue-black crystals were distinguished in the cavities of the "iron spots." Even in the other two products suggestions that such crystals in a minute form may be present, were obtained. In samples of the five bricks unaffected in the test, the cavities were brown in colour—except in one instance, where solid black spots were noted—and no suggestion of blue-black crystals could be found. Such observations suggest that these crystals are in some way connected with the disintegrating tendency.

(5) The Action of Carbon Monoxide on Refractory Materials. Part II.

Further Experiments on the Disintegration of Fireclay Products by Carbon Monoxide.

By W. Hugill, M.Met., F.R.M.S., H. Ellerton, and A. T. Green, F.Inst.P., A.I.C.

Bull. B.R.R.A., No. 26, pp. 37-43, 1931.

General.

An examination of the results of the work reported in Part I. of this study indicated that it was desirable to obtain data from experiments of longer duration. Accordingly specimens from the same batches of products were subjected to the action of the monoxide for 200 hours and notes of their behaviour taken at intervals during this period. Some further work on the ferruginous constituent, separated by the use of bromoform, has also been completed.

Observations.

From the experiments of 20 hours' duration it is noted that materials C, F. I, J, and K did not show signs of disintegration. In the experiments of 200 hours' duration, C, F, and J resisted breakdown, although, in the

case of C, the matrix was uniformly darkened, and a small crack appeared after 50 hours' treatment. Thus, so far as our experiments have gone, only three out of the eleven original products have entirely resisted disruption. In the experiments with materials I and K, cracks began to appear after about 105 hours' treatment, and disintegration was fairly complete after 150 and 130 hours respectively. The cracks appeared to have started at two or three isolated spots, where the nodules of ferruginous matter were segregated. Particularly was this so with K, in which two detectable "iron spots" were the primary cause of disruption. Again, in the case of B, which contains a comparatively very small quantity of "iron," disintegration was localized at two or three "iron spots."

Materials D, G, and H have suffered most in these tests. Although one sample of D, which seemed to be harder fired than the majority of the specimens in this batch, resisted disintegration for 200 hours, another check specimen showed complete breakdown in 20 hours. The other materials form an intermediate group, in which signs of disruption appear after longer periods of experiment, or in which the amount of disintegration is not excessive. Table 1, which is based on the preceding observations, gives an order of resistance to the attack of carbon monoxide, together with other pertinent data.

TABLE 1.—*Suggested Order of Resistance to Disintegration.*

—	Materials Completely Resisting Disintegration.			Intermediate Group.					Materials Showing Excessive Disruption.		
Brick order .	F	J	C	I	K	E	A	B	D	H	G
Per Cent. Fe_2O_3 by analysis .	2·88	2·34	3·75	2·50	2·52	2·40	1·69	1·33	3·12	2·40	5·00
Permeability at ordinary temps. . .	0·528	0·101	0·028	0·134	0·072	0·152	..	0·020	0·191	..	..

An analysis of the factors governing disintegration suggests that the most important may be (1) the character of the ferruginous matter; (2) the permeability of the brick; and (3) the strength and elasticity of the matrix of the brick, together with the extent of the adhesion of the grog in the mass, *i.e.*, the "internal strength" of the material. Our experiments point to the fact that the character of the ferruginous matter masks the influences of the other factors. Whilst no data on the "internal strength" of the materials of experiment is available, a study of the texture did not give the impression that some of the specimens showing easy disintegration were deficient in this respect. In Table 1 permeability data for most of the products are reported. Although these data are not complete, they are sufficient to show that there is no obvious relationship between permeability and disintegration by carbon monoxide. In illustration, it can be noted that material B has both the lowest "iron" content and the lowest reported value for permeability, and yet, in our experiments, it shows definite signs of disintegration. F, with a very high value for permeability, does not disintegrate. On the other hand, D, with a very high permeability value, does break down in the test. These remarks serve to emphasize the potency of the nature of the ferruginous matter in causing disintegration.

An Examination of the Fractions Separated by Bromoform.

The gravity method of mineral separation by the use of heavy liquids, in this case bromoform, has been used in order to obtain two fractions from ground samples of the materials of experiment. The heavier fraction appeared to consist of black specks and, as the analysis indicates, is of a ferruginous character. The analysis of this extract from material G is SiO_2, 14·80 per cent.; Al_2O_3, 11·38 per cent.; Fe_2O_3, 71·02 per cent.; TiO_2, 1·08 per cent. This extract from material G is designated fraction A. Fraction B, being lighter than the liquid, consisted of the normal aluminosilicate ground mass of the brick. These two finely-divided fractions together with the ground samples of another brick of the batch G were subjected to the action of carbon monoxide for 80 hours, weighings being taken at the end of each interval of six hours. The resulting increase in weight are shown in Table 2.

TABLE 2.

Time in Hours.	Per Cent. Carbon Deposition.		
	Fraction A	Fraction B.	Original Brick.
6	73·2	0·19	2·7
12	107·7	0·47	3·3
18	135·1	0·62	3·8
24	146·6	0·76	4·2
30	154·8	0·84	4·5

The data certainly show that, in the case of material G, the ferruginous fraction, which can be separated by the use of bromoform as a gravity separator, is responsible for the carbon deposition, and, consequently, for the eventual disintegration of the brick.

(6) REFRACTORY JOINTING CEMENTS.

By A. T. Green, F.Inst.P., A.I.C., F. Wheeler, and H. Booth.

Interim Report.

General.

It is well-known that, in certain high-temperature installations, particularly including the gas retort, the cement joints exert a considerable influence on the ultimate durability of the plant. Consequently, the properties of these cements demand rigid control. During the past year, investigations of the properties of both commercial and laboratory-prepared cements have been in progress. Although this work is not completed, reference may here be made to one aspect of these investigations.

At the commencement of the work, it was realized that the refractoriness-under-load test with modifications could be applied with advantage to this study. This test can be used to indicate the temperature-range, at which contraction of the cement becomes appreciable, and thus, to define the temperature limits of its structural stability. These data are important, particularly in silica retort work, since excessive contraction of the cement has been known to alter the alignment or position of certain portions of the retort setting with final disastrous results. This can be comprehended from the fact that in the construction of a length of 20 ft. of vertical retort, there may be 5 to 8 in. or more of cement.

The report details a few of the results obtained. A full discussion of the completed results will appear in a future paper.

(7) OTHER WORK IN PROGRESS OF INTEREST TO GAS ENGINEERS.

Hot Patching of Retorts.

Work on hot-patching cements has now been in progress for some time. A good number of possible mixtures has been evolved and tested in the laboratory. The difficulties are obviously connected with the ingredients, which must give "stickability" over a wide range of temperature, without the possibility of injury to the retort. With the help of the Institution, arrangements have been made to carry out tests with probable hot-patching cements on different types of retort settings in different parts of the country. The work has now reached the stage when a start can be made with these plant investigations.

There are, at least, two aspects of hot-patching to receive consideration. In the first place, a method of hot-patching is used to fill up small holes in the retort structure, probably at the joints, which result in gas leakage. The cement gun is used for this purpose, and appears to give good results, particularly, if it is used after every scurfing. This seems to be the significance of the term "hot-patching" in certain sections of the industry. To some gas engineers, however, it would appear that the methods of hot-patching must be capable of a far more extensive application, in fact, to large areas of the retort, which, say, have shown pronounced flaking. This, of course, is a very difficult proposition. It is obvious, therefore, that these two aspects of hot-patching must be clearly differentiated.

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CONTENTS

EDITORIAL NOTES.

A GLANCE AT THE CONTENTS . . . 299
The Turning Point 300
A Big Figure Election 300
Views from Yorkshire 300
Oxide Purification 301
Importance of Public Lighting 301

CORRESPONDENCE.

Our National Organizations 302
Future Possibilities of Fuel Utilization" . 302
Benzole *v.* Trams 302
Hydrogenation 303

Forthcoming Engagements 301
Personal—
Changes at Ipswich—Mr. Frank Prentice Becomes a Director 303
Presentation to Mr. Wm. Cash 303
Obituary—
Alderman Sir Joseph Calvert 304
Mr. W. H. Hammond 304

NEWS OF THE WEEK.

Paragraphs 304–5
Nation Wide "Buy British" Campaign—An Opportunity for Gas Showrooms . . . 305
Evening Star Chapter, No. 1719 305
Institution of Gas Engineers 305
The Health of the Citizen 305
Sir Arthur Duckham and the World Crisis . 305
Some Further Potential Investments . . . 306

SPECIAL ARTICLES, &c.

An Example of Good Window Display . . 306
Reviews 307
In Continental Countries—Abstract Translations from the Technical Press of France and Germany 308
Lincoln's New Gasholder 308
American Gas Association Convention . . 309
Gas in the Home 310

"JOURNAL" TECHNICAL RECORD.

Midland Junior Gas Association—
Visit to the Works of Messrs. Westwood & Wright, Ltd., Dudley 310
Manchester District Institution of Gas Engineers—
Oxide of Iron Purification of Coal Gas. By R. H. Clayton, B.Sc., H. E. Williams, and H. B. Avery, M.Sc.Tech. 311
Yorkshire Junior Gas Association—
General Business 315
Address of Mr. H. Singleton 315
Progress of Pipe Joint Research. By K. R. Knapp 317
Notes on Plants and Proce ses 319

MISCELLANEOUS.

Gas Acts (1920 and 1929) Orders 317
Metropolitan Gas Companies' Testings . . 320
Market Harborough Gas-Works 320

GAS MARKETS AND MANUFACTURES.

Stock Market Report 320
Current Sales of Gas Products 320
Contracts Advertised To-Day 320

Stock and Share List 321

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For Advertisers' Index—see p. 326

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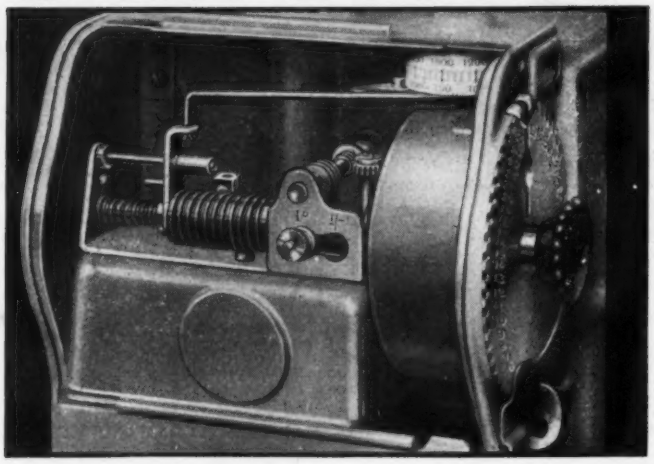

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